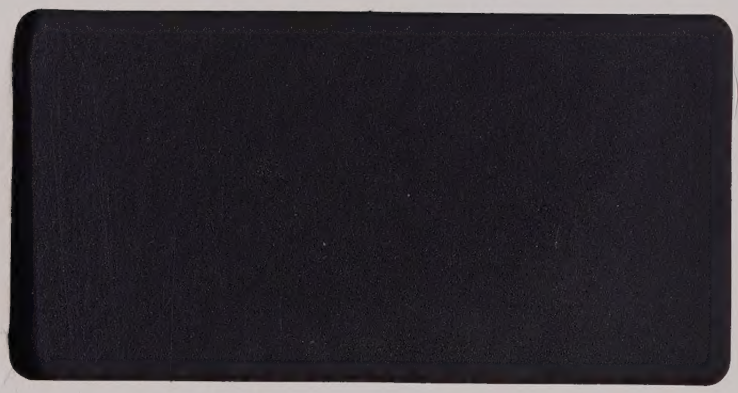
INSTRUCTION MANUAL

MODEL 148

NANOVOLTMETER

KEITHLEY INSTRUMENTS, INC.



INSTRUCTION MANUAL

MODEL 148

NANOVOLTMETER

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof which, within a year after shipment, proves defective upon examination. We will pay domestic surface freight costs.

To exercise this warranty, call your local field representative or the Cleveland factory, DDD 216-248-0400. You will be given assistance and shipping instructions.

REPAIRS AND RECALIBRATION

Keithley Instruments maintains a complete repair service and standards laboratory in Cleveland, and has an authorized field repair facility in Los Angeles and in all countries outside the United States having Keithley field representatives.

To insure prompt repair or recalibration service, please contact your local field representative or the plant directly before returning the instrument.

Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

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* Change Notice

* Yellow Change Notice sheet is included only for instrument modifications affecting the Instruction Manual.

FIGURE 1. Keithley Instruments Model 148 Nanovoltmeter.

SECTION 1. GENERAL DESCRIPTION

1-1. GENERAL.

a. The Keithley Model 148 Nanovoltmeter conveniently measures dc potentials from 10 nanovolts (10×10^{-9} volts) to 100 millivolts full scale. It makes accurate and sensitive measurements without painstaking methods often previously required. Meter accuracy is 2% of full scale on all ranges. Noise is less than 1 nanovolt peak-to-peak on the 10-nanovolt range. Zero drift is less than 10 nanovolts per 24 hours after warm-up. On the three most sensitive ranges, line-frequency rejection is greater than 1000:1.

b. For reliable and versatile use, the Nanovoltmeter is of solid-state design, except for the first two input stages. It has high line isolation and battery or line operation.

1-2. FEATURES.

a. Battery operation permits complete isolation from power line, eliminating many grounding problems. Battery operation also allows flexibility and convenience in use. The Model 148 automatically recharges the battery if needed when the ac power cord is connected.

b. The Nanovoltmeter has a ± 1 volt at 1 milliampere output at full-scale meter deflections for driving a recorder or oscilloscope. Accuracy is 1% of full scale for output.

c. A zero suppression circuit permits measuring small changes in a larger dc signal.

1-3. APPLICATIONS.

a. The Model 148 Nanovoltmeter measures very small dc potentials or small changes in dc potentials from low impedance sources. These are found in fundamental or applied research, laboratory standards work, cryogenic experiments and instrument development for space research. It can also serve as an amplifier in these uses.

b. Typical uses include measuring small temperature differences and small temperature changes indicated by thermocouple outputs, small changes in conductance, super conductivity in the 10^{-6} ohm range, and thermopile outputs used in narrowband spectrum analysis. Other uses are determining the thermoelectric power of metals, conducting Hall effect studies, and making Bolometer measurements. Also, the Model 148 is suited for use with potentiometers, ratio sets and resistance bridges, including Wenner, Wheatstone and Kelvin Double bridges. It can be used to make 4-terminal resistance measurements.

.1-4. SPECIFICATIONS.

RANGES: 10 nanovolts (10×10^{-9} volt) full scale to 100 millivolts on a zero-center meter. Eighteen overlapping ranges in 1x and 3x steps.

ACCURACY:
Meter: 2% of full scale on all ranges.
Output Terminals: 1% of full scale on all ranges.
Note: Accuracy excludes noise considerations.

STABILITY: Within 10 nanovolts per 24 hours after one-hour warm-up with reasonably constant ambient temperature. Long term drift is non-cumulative.

INPUT NOISE (with input shorted): Less than one nanovolt (10^{-9}v) peak-to-peak on most sensitive range. Noise as a percent of full scale is less on less sensitive ranges, and is negligible as seen at the meter on the 0.3-microvolt and higher ranges.

RESOLUTION: Better than one nanovolt on most sensitive range.

INPUT RESISTANCE, MAXIMUM SOURCE RESISTANCE, AND LINE FREQUENCY REJECTION:

Range	Input Resistance Greater Than, Ohms	Maximum Source[1] Resistance, Ohms	Line Frequency[2] Rejection
0.01 microvolt	1k	10	3000:1
0.03 microvolt	3k	30	1000:1
0.1 microvolt	10k	100	1000:1
0.3 microvolt	30k	300	500:1
1.0 microvolt	100k	1k	300:1
3.0 to 100.0 microvolts	300k	3k	100:1 decreasing to 50:1
0.01 to 100 millivolts	1M	10k	100:1 decreasing to 5:1

Notes: [1]Operation at source resistances higher than maximum is possible with some degregation of other specifications.

[2]Ratio of impressed peak-to-peak line frequency voltage at input to indicated dc voltage.

RISE TIME (10% to 90% of full scale): 30-nanovolt range: 2 seconds when source resistance less than 10% of maximum; 4 seconds using maximum source resistance. Rise time is above 3 times longer on 10-nanovolt range.

0.1-microvolt to 100-millivolt ranges: 0.5 second when source resistance less than 10% of maximum; three seconds using maximum source resistance.

ZERO SUPPRESS: Up to at least 100 microvolts on microvolt ranges, and up to at least 100 millivolts on millivolt ranges available. Stability such that 100 times full scale may be suppressed.

RECORDER OUTPUT:

Output: ±1 volt dc at one milliampere for full-scale meter deflection on any range.

Output Resistance: Less than five ohms within amplifier pass band.

Output Ripple (94 cps and modulation products): Less than 2% of full scale with input shorted.

Output Noise: Input noise times gain.

AMPLIFIER GAIN: The gain as an amplifier varies from a maximum of 10^8 to a minimum of 10, corresponding to range selected.

COMMON MODE REJECTION: 60 or 50 cps: greater than 160 db.
120 or 100 cps: greater than 140 db.

ISOLATION: Low to ground: Greater than 10^9 ohms, shunted by 0.05 microfarad. On battery operation, may be completely isolated.

CONNECTORS: Input: Special low-thermal receptacle.
Output: Microphone type receptacle.

TUBE COMPLEMENT: Two CK512AX.

TRANSISTOR COMPLEMENT: Six A1294, four 2N1183, twenty-four 2N1381, one 2N1535, five 2N1605A, two 2N651.

POWER: Line operation: 105-125 volts or 210-250 volts, 60 cps, 16 watts. 50-cps models available.

Battery Operation: Rechargeable nickel-cadmium 6-volt battery pack. 14 hours full charge to complete discharge. For maximum battery life, recommended battery operation for no more than eight consecutive hours before recharge.

ACCESSORIES SUPPLIED: Model 1481 Low-Thermal Input Cable with alligator clips; mating Output plug; mating Demodulator Test plug; adapter for 2-wire receptacles.

DIMENSIONS: 5-1/4 inches high x 17-1/2 inches wide x 10-1/2 inches deep.

NET WEIGHT: 20 pounds.

1-5. ACCESSORIES AVAILABLE. The following accessories increase the measuring convenience of the Model 148. Refer to Section 2 for operating and installing instructions.

a. Model 1481 Low-Thermal Input Cable contains two alligator clips and an input plug. The Cable uses only pure copper components and crimp connections to provide convenient low-thermal connections to the Nanovoltmeter.

b. Model 1482 Low-Thermal Input Cable is similar to the Model 1481, except it has bare copper leads instead of alligator clips.

c. Model 1483 Low-Thermal Connection Kit contains a crimp tool, cable, pure copper lugs and other hardware for making experimental setups which need the best low-thermal connections. The parts list is in Section 5.

d. Model 1484 Refill Kit contains replacement parts for the expendable items found in Model 1483 Kit. The parts list is in Section 5.

e. Model 1485 is a female low-thermal input connector.

f. Model 1486 is a male low-thermal input connector. It can be used as a low-thermal shorting plug when a short length of copper wire is crimped between the two pins. See paragraph 2-6.

g. Model 4002 Rack Mounting Kit converts the Nanovoltmeter from a bench-mounted unit to rack mounting. The Kit contains a cover and two rack angles. As a rack model, the Nanovoltmeter is 5-1/4 inches high x 19 inches wide x 10-1/2 inches deep. Refer to paragraph 2-17 for assembly instructions.

1-6. EQUIPMENT SHIPPED. The Model 148 Nanovoltmeter is factory-calibrated and is shipped with all components in place. All units are shipped for bench use. Model 4002 Kit may be ordered for rack mounting; refer to paragraph 2-17 for assembly instructions. The shipping carton also contains the Instruction Manual, the Model 1481 Low-Thermal Input Cable, mating plugs for the Output and Demodulator Test receptacles, and a 2-wire power line adapter.

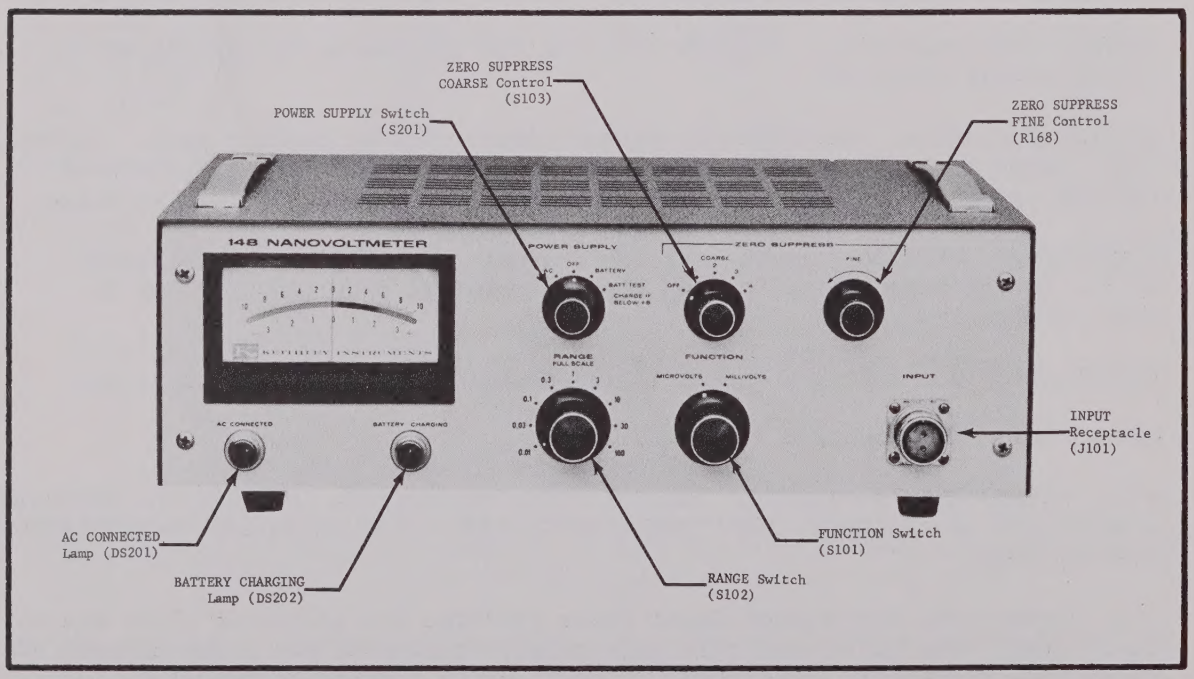


FIGURE 2. Model 148 Front Panel Controls. Circuit designations refer to Replaceable Parts List and schematic diagrams.

SECTION 2. OPERATION

2-1. FRONT PANEL CONTROLS. (See Figure 2.)

a. AC CONNECTED Lamp. The Lamp is lit whenever the unit is connected to the ac line and the POWER SUPPLY Switch is in the AC or OFF position.

NOTE

The AC CONNECTED Lamp indicates only that the instrument is connected to the ac power line; it does not indicate that the Nanovoltmeter is operating. Also, when the POWER SUPPLY Switch is turned from AC to OFF, a difference in Lamp brightness is normal.

b. BATTERY CHARGING Lamp. When lit, this Lamp indicates the battery is charging. The charge current determines its brightness. If the lamp is not lit, then the battery is charged.

c. POWER SUPPLY Switch. The Switch controls the mode of operation for the power supply.

1. AC position: The Nanovoltmeter will operate from the ac power line. The battery will be charged if needed; then, the BATTERY CHARGING Lamp will light.

2. OFF position: The Model 148 is not operating. However, the battery will be charged, if needed and if the power cord is connected.

3. BATTERY position: The Nanovoltmeter is operated from its battery. The ac power line is internally disconnected; the AC CONNECTED Lamp is off; the battery cannot be charged.

4. BATT.TEST position: When the POWER SUPPLY Switch is held in this position, the Model 148 shows the state of the battery charge directly on its meter. All circuits within the instrument are the same as for battery operation except at the meter terminals.

POWER SUPPLY Switch Setting	Power Cord Connected	AC CONNECTED Lamp	BATTERY CHARGING Lamp (If battery is charging)
AC	Yes	On	On
OFF	Yes	On	On
	No	Off	Battery cannot be charged
BATTERY	Yes	Off	Battery cannot be charged
	No	Off	Battery cannot be charged
BATT TEST	Yes	Off	Battery cannot be charged
	No	Off	Battery cannot be charged

TABLE 1. Indicating Lamps and POWER SUPPLY Switch Settings. The table shows the relationship between the front panel lamps, the power cord and the POWER SUPPLY Switch setting.

d. RANGE Switch. The RANGE Switch selects the full-scale meter sensitivity (either microvolts or millivolts) for one of nine ranges, from 0.01 to 100.

e. FUNCTION Switch. The FUNCTION Switch selects the function — MICROVOLTS or MILLIVOLTS — which is to be measured.

f. ZERO SUPPRESS Controls. Two controls determine the amount of zero suppression.

1. The COARSE Control disconnects the suppression circuit (in OFF position) or selects one of four suppression voltages in decade steps. Refer to Table 3.

2. The FINE Control is a continuously variable adjustment for the suppression voltage set by the COARSE Control. It adjusts the range between the positive and negative values of the maximum voltage set by the COARSE Control.

g. INPUT Receptacle. The INPUT Receptacle is of a special low-thermal design. Use only the Models 1481, 1482 and 1486 for mating connectors.

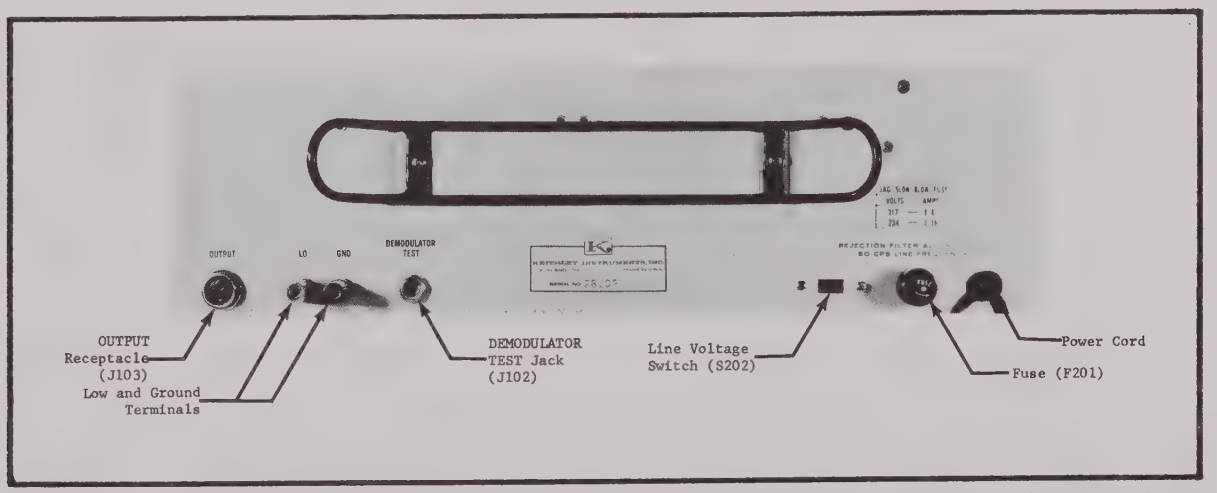


FIGURE 3. Model 148 Rear Panel Controls and Connections. Circuit designations refer to Replaceable Parts List and schematic diagrams.

2-2. REAR PANEL CONTROLS AND CONNECTIONS.

a. Line Voltage Switch. The screwdriver-operated slide switch sets the Model 148 for 117 or 234-volt ac power lines.

b. Fuse.

1. For 117-volt operation, use a 3 AG or MDL Slow-Blow 1/8-ampere fuse.

2. For 234-volt operation, use only a MDL Slow-Blow 1/16-ampere fuse.

c. Power Cord. The 3-wire power cord with the NEMA approved 3-prong plug provides a ground connection for the cabinet. An adapter for operation from 2-terminal outlets is provided.

NOTE

A note above the power cord shows the ac power line frequency for which the rejection filter is adjusted. The instrument will work at any line frequency from 50 to 1000 cps, but ac rejection is best at the indicated frequency.

d. DEMODULATOR TEST. A phone jack provides access to the demodulator for test purposes.

e. OUTPUT. The OUTPUT Receptacle provides $\pm$1 volt at one milliampere for a full-scale meter deflection on any range.

f. GND and LO Terminals. The ground terminal (GND) is connected to the chassis and the third wire of the power cord. The low terminal is connected to circuit ground and the low side of the input connection.

2-3. MODE OF OPERATION. The Model 148 operates either from an ac power line or from its battery. For most uses, it functions well from ac. Use battery operation, however, if the ac power line will create ground loop or isolation problems. Isolation from low to ground is complete for battery operation when the power cord is disconnected; it is greater than 10^9 ohms with the power cord connected. Also use battery operation to reduce the 8-cps ripple which may appear at the output with the input shorted in ac operation. See paragraph 2-13.

NOTE

Before using the battery operation, thoroughly read paragraph 2-4. Inproper battery operation can damage the battery pack and lead to inaccurate measurements.

2-4. BATTERY OPERATION.

a. The Model 148 is supplied with a rechargeable 6-volt, 4 ampere-hour nickel-cadmium battery pack. Recommended: Do not use the battery more than eight consecutive hours without recharging. At this discharge rate, the battery should last about 1000 recharge cycles.

NOTE

Permanent damage to the battery pack occurs if it is used for more than 14 consecutive hours without recharging. At this discharge rate, the recharge cycles are greatly reduced. Before using the Model 148, check the state of the battery charge.

b. Check the battery charge before making a measurement. Hold the POWER SUPPLY Switch in the BATT. TEST position. The minimum acceptable charge is a meter indication of +8; full charge is shown by the BATTERY CHARGING Lamp not being lit. Recharge if needed. Otherwise, battery operation is the same as for the ac power line operating mode; refer to paragraph 2-5.

NOTE

When the battery is used beyond its capacity, two effects are seen. There is a shift in zero offset from ac to battery operation. Also, the power supplies do not regulate and high ripple voltages appear at the supply outputs. (See paragraph 4-7.)

c. To recharge the battery, connect the power cord to an ac power line. Turn the POWER SUPPLY Switch to AC or OFF. The BATTERY CHARGING Lamp will light. The battery will be charged only if needed, and the circuit automatically prevents it from being overcharged.

d. It is suggested that the battery be used during the day and be recharged at night. Leave the instrument always connected to the ac power line; then turn the POWER SUPPLY Switch to OFF at night. After a fully charged battery is used for eight consecutive hours, it will recharge within 14 hours. Leaving the power cord connected has little effect on the isolation: 10^9 ohms with the POWER SUPPLY Switch in BATTERY position and the low-ground link disconnected.

2-5. OPERATING PROCEDURES.

a. Set the front panel controls as follows:

POWER SUPPLY Switch	OFF
FUNCTION Switch	MILLIVOLTS
RANGE Switch	100
ZERO SUPPRESS COARSE Control	OFF

NOTE

Make sure the ZERO SUPPRESS COARSE Control is OFF. If it is not, a suppression voltage is introduced, causing an error in measurements.

b. Connect the unknown voltage source to the INPUT Receptacle. Refer to paragraph 2-6 for suggestions.

c. Check the voltage shown on the rear panel Line Voltage Switch; connect the Model 148 to the ac power line. Make sure the frequency shown above the power cord is the frequency of the ac power line. At this point, the AC CONNECTED Lamp will light, as will the BATTERY CHARGING Lamp if the battery is being charged. If the circuit low is to be at ground, put the low-ground link between the LO and GND terminals on the rear panel.

d. Turn the POWER SUPPLY Switch to the desired mode of operation, AC or BATTERY.

e. Increase the sensitivity of the Model 148 until the meter shows the greatest on-scale deflection.

1. Check the source resistance to make sure it is within the maximum value specified for the range being used. (See Table 2.) If the maximum resistance is exceeded, the Model 148 may not be within its specifications.

2. Zero offsets with the Zero Suppress Controls off will vary with the quality of the circuit's thermal construction. See paragraph 2-14. When a Model 1486 with a copper-wire short is on the Model 148 INPUT Receptacle, offset should be less than 0.2 microvolt.

3. Shifts in source resistance also affect the zero offset, if the source resistance approaches the maximum value given in Table 2. This effect is negligible for source resistances less than 10% of the maximum value.

4. If the input is left completely open-circuit, the meter will drift off scale on any range.

5. Refer to Table 4 if problems exist during the measurement.

Range	Input Resistance Greater Than	Maximum Source Resistance	Minimum Line Frequency Rejection
0.01 microvolt	1 kΩ	10 Ω	3000:1
0.03 microvolt	3 kΩ	30 Ω	1000:1
0.1 microvolt	10 kΩ	100 Ω	1000:1
0.3 microvolt	30 kΩ	300 Ω	500:1
1 microvolt	100 kΩ	1 kΩ	500:1
3 microvolts	300 kΩ	3 kΩ	100:1
10 microvolts	300 kΩ	3 kΩ	decreasing
30 microvolts	300 kΩ	3 kΩ	to
100 microvolts	300 kΩ	3 kΩ	50:1
0.01 millivolt	1 MΩ	10 kΩ	100:1
0.03 millivolt	1 MΩ	10 kΩ	50:1
0.1 millivolt	1 MΩ	10 kΩ	20:1
0.3 millivolt	1 MΩ	10 kΩ	20:1
1 millivolt	1 MΩ	10 kΩ	20:1
3 millivolts	3 MΩ	30 kΩ	10:1
10 millivolts	5 MΩ	50 kΩ	10:1
30 millivolts	5 MΩ	50 kΩ	5:1
100 millivolts	5 MΩ	50 kΩ	5:1

TABLE 2. Model 148 Input Resistance, Maximum Source Resistance, and Minimum Line Frequency Rejection by Range. The rejection is the ratio of impressed peak-to-peak line frequency (50 or 60 cps) voltage at input to the indicated dc voltage.

f. Three millivolt and microvolt ranges overlap: 0.01, 0.03 and 0.1 millivolts and 10, 30 and 100 microvolts. Use the millivolt ranges when the source resistance is high or if large 60-cps fields are present. The microvolt ranges are more convenient to use if subsequent measurements require more sensitive ranges. Refer to Table 2 for maximum source resistance and line frequency rejection by range.

g. At low levels, spurious emf's may be generated simply by contact between the input leads and the circuit under test. If possible, always leave the instrument connected, and adjust the zero after establishing a zero reference in the apparatus under test. For example, in bridge measurements,

disconnect the bridge exciting voltage; or with a phototube, shield the tube from light.

2-6. ACCESSORIES FOR INPUT CONNECTIONS.

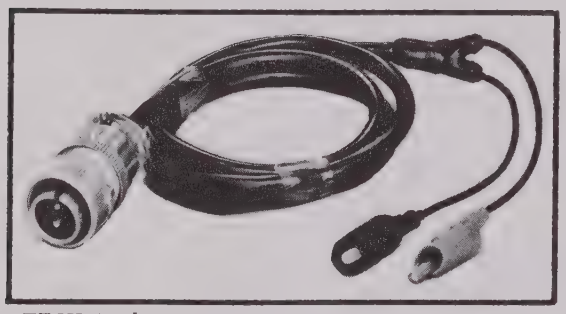


FIGURE 4. Model 1481 Low-Thermal Input Cable.

a. The easiest way to connect the voltage source to the Model 148 input is with the Model 1481 Low-Thermal Input Cable supplied with the instrument. Use the Cable for temporary setups, for measurements at several points, and when fast connections are needed. The Model 1481 connects directly to the INPUT Receptacle.

b. Where more permanent setups are possible or where very low thermal connections are needed, use the Model 1482 Low-Thermal Input Cable. It is similar to the Model 1481, except it has bare copper leads instead of alligator clips. Clean the bare wire with a non-metallic abrasive, such as Scotch Brite or its equivalent, before making the connection. Crimp connections to the voltage source, as possible with the Model 1483 Kit, provide the best low-thermal connections.

c. If cadmium solder is used for a connection, make sure the soldering iron used is clean and that it has not been used with regular solder before. Use only rosin solder flux. If possible, heat sink all cadmium-soldered joints together to reduce generated thermal emf's.

FIGURE 5. Model 1483 Low-Thermal Connection Kit.

d. Use crimp connections with copper wire and lugs for the best low-thermal joints. The Model 1483 Low-Thermal Connection Kit contains a crimp tool, shielded cable, an assortment of copper lugs, copper wire, cadmium solder and nylon bolts and nuts. It is a complete kit for making very low-thermal measuring circuits. The Kit enables the user of the Model 148 to maintain the high thermal stability of the Nanovoltmeter in his own circuit.

e. The Model 1486 male low-thermal input connector is for connecting custom-made circuits to the Model 148. It also makes a good low-thermal shorting plug for testing the Nanovoltmeter: crimp a short length of pure copper No. 18 or No. 20 wire between the two pins of the connector.

f. Other available accessories are: The Model 1484 Refill Kit, which contains replacement parts for the Model 1483. The Model 1485 female low-thermal input connector to use with the Model 1481, 1482 or 1486 for building shielded low-thermal circuits.

2-7. ZERO SUPPRESS OPERATION.

a. Purpose: The zero suppression circuit cancels any constant voltage in order to use a more sensitive range to observe a superimposed signal. Up to 100 times full scale may be suppressed on the ranges from 0.1 millivolt to 0.01 microvolt. For example, the Model 148 can measure changes of less than one microvolt in a 100-microvolt steady signal on its 1-microvolt range.

b. Suppression Voltages Available: The COARSE Control sets the suppression voltage to one of eight values, depending upon its setting and the FUNCTION Switch setting. (Refer to Table 3.) The FINE Control continuously adjusts the voltage between the positive and negative value of COARSE Control setting. For example, if the COARSE Control is at 1 for a suppression voltage of 0.24 millivolt, the FINE Control adjustment span is from -0.24 mv to 0 to +0.24 mv.

FUNCTION Switch Setting	ZERO SUPPRESS COARSE Control Setting	Maximum Suppression Voltage
MICROVOLTS	1	0.24 microvolt
MICROVOLTS	2	1.2 microvolts
MICROVOLTS	3	12 microvolts
MICROVOLTS	4	120 microvolts
MILLIVOLTS	1	0.24 millivolt
MILLIVOLTS	2	1.2 millivolts
MILLIVOLTS	3	12 millivolts
MILLIVOLTS	4	120 millivolts

TABLE 3. Suppression Voltage by Control Settings. The zero suppression voltage shown is the maximum value, ±15%, for each FUNCTION Switch and COARSE Control setting.

c. Operation.

1. Keep the COARSE Control in OFF position. Adjust the RANGE and FUNCTION Switches for the most sensitive meter reading.

2. Completely turn the FINE Control in the direction opposite to the meter deflection (counterclockwise for positive deflections and clockwise for negative deflections).

3. Increase the COARSE Control setting until the meter needle passes through zero. Adjust the FINE Control for zero deflection.

4. Set the RANGE Switch to a more sensitive range, up to 100 times more sensitive than the original range (four RANGE Switch positions). Readjust the FINE Control to zero, if necessary.

NOTE

On the highest zero suppression range — 120 millivolts maximum — a zero offset will be apparent when changing the RANGE Switch settings. On this zero suppression range, first set the RANGE Switch to the range intended to be used. Then zero the meter with the ZERO SUPPRESS FINE Control. This offset is introduced only when the ZERO SUPPRESS COARSE Control is set to 4 and the FUNCTION Switch is set to MILLIVOLTS. There is no significant offset on any other zero suppression range.

2-8. DIFFERENTIAL MEASUREMENTS.

a. The Model 148 will measure the difference between two voltages, neither or which is at power line ground. It can be floated up to ±400 volts off ground in ac operation. When the Model 148 is battery operated it is completely isolated from line.

NOTE

Unplug the Model 148 power cord and use battery operation before measuring a source which is more than ±400 volts instantaneous off ground. Damage to the instrument can result if the power line is connected under these conditions.

CAUTION

The front panel controls are electrically connected to the case. If the power cord is unplugged, the case may be at a voltage equal to the off-ground voltage. Use necessary safety precautions.

b. For best results in making differential measurements, follow the steps below:

1. Remove the link from the LO or GND terminal on the rear panel.

2. Connect the voltage source to the Nanovoltmeter input. Make measurements as described in paragraph 2-5. The zero suppress controls may be used for differential measurements. Do not ground any recorders used with this operation, since the low of the Model 148 output is no longer grounded.

3. If power line frequency pickup is a problem, battery operation usually provides better results.

2-9. RECORDER OUTPUT. The output of the Nanovoltmeter for a full-scale meter deflection on any range is ±1 volt at one milliampere. Accuracy is 1% of full scale. Output resistance is less than 5 ohms within the amplifier pass band. Output may be used during both ac and battery operation. If the Model 148 is used for differential measurements, do not ground the recorder connected to the output.

a. When recording the Keithley Model 370 Recorder offers complete compatibility with the Model 148. The output is sufficient to drive the Model 370 without the use of any recorder preamplifiers. The Model 370 allows maximum capability of the Model 148. It has 1% linearity, 10 chart speeds and can float up to ±500 volts off ground. Using the Model 370 with the Model 148 avoids interface problems which may be encountered between a measuring instrument and a recorder.

b. The Model 370 is very easy to use with the Model 148. All that is necessary is connecting the two units and adjusting an easily accessible control for full-scale recorder

Trouble (seen on meter)	Possible Cause	Refer to
Change in offset between ac and battery operation	Low Battery	paragraph 2-4
Very slow response time	High source resistance	paragraph 2-12
	Improper shielding	paragraph 2-13
Excessive drift	Thermal emfs	paragraph 2-14
	Improper connection to input	paragraph 2-15
Excessive noise or needle instability	High source resistance	paragraphs 2-11,2-12
	Improper shielding	paragraph 2-13
	Improper connection to input	paragraph 2-15
	Thermal emfs	paragraph 2-14
Excessive temperature sensitivity	Thermal emfs	paragraph 2-14
Presence of large, constant signal	Zero Suppress Controls On	paragraph 2-5
	Thermal emfs	paragraph 2-14
	Improper connection to input	paragraph 2-15
Excessive 8-cps beat at output or meter	Improper location or poor magnetic shielding	paragraph 2-13

TABLE 4. Troubleshooting Operating Procedures. The Table gives some possible sources of errors while using the Model 148 and refers to instructions to correct the situation.

deflection. The furnished Model 3701 Input Cable mates with the output connector on the Model 148. On the most sensitive ranges of the Model 148, under some conditions, an 8-cps beat may appear. This condition can be eliminated by mounting a 100-microfarad capacitor across pins 14 and 17 in the back of the Model 370 Recorder.

2-10. ACCURACY CONSIDERATIONS. For sensitive measurements — 10 millivolts and below — other considerations beside the voltmeter affect accuracy. The Model 148 reads only the signal received at its input; therefore, it is important that this signal be properly transmitted from the source. The following paragraphs indicate factors which affect accuracy: thermal noise, loading, shielding, thermal emfs and circuit connections. Table 4 also offers a quick reference to correct troubles which may occur.

2-11 THERMAL NOISE.

a. The lower limit in measuring small potentials occurs when the Johnson noise, or thermal agitation, becomes evident. The amount of noise present in the source is shown in the following equations.

1. The thermal noise in any ideal resistance can be determined from the Johnson noise, equation:

$$E_{rms}^2 = 4\ k\ T\ R\ F \qquad \text{Eq. 1}$$

where E_{rms} is the rms noise voltage developed across the voltage source;
T is the temperature in degrees Kelvin;

R is the source resistance in ohms;
F is the amplifier bandwidth in cps;
k is the Boltzmann constant (1.38×10^{-23} joules/°K).

For an ideal resistance at room temperature (300°K), equation 1 simplifies to

$$E_{rms} = 1.29 \times 10^{-10} (R F)^{1/2} \qquad \text{Eq. 2}$$

2. Peak-to-peak meter indications are of more interest than the rms value. Experimentally, the peak-to-peak Johnson noise is about five times the rms value. At room temperature, equation 2 becomes

$$E_{pp} = 6.45 \times 10^{-10} (R F)^{1/2} \qquad \text{Eq. 3}$$

where E_{pp} is the peak-to-peak noise voltage developed across the voltage source.

3. The Model 148 bandwidth, F, can be estimated from the response speed, t_r, by:

$$F = 0.35/t_r \qquad \text{Eq. 4}$$

The response speed varies with the range used and the source resistance. On the 0.1-microvolt range when the source resistance is less than 10 ohms, for example, the bandwidth is greater that 0.7-cps. The maximum specified response speed for this situation is 0.5 second, so the 0.7-cps bandwidth is a minimum value.

4. As an example, determine the Johnson noise of a 10-ohm ideal resistor. Measured with the Model 148 on the 0.1-microvolt range and using equation 3, this becomes 17.1×10^{-10} volts peak-to-peak or 1.71 nanovolts peak-to-peak minimum.

b. In general, good wirewound or low-noise metal-film resistors approximate ideal resistors, and equations 2 and 3 are nearly correct. If the source resistance is composed of other materials, it may be necessary to include other terms in the equations to account for flicker, 1/f, and current noise over and above the thermal noise.

c. As seen in equations 2 and 3, the noise of even low resistance values becomes significant in the microvolt region. The noise in non-ideal resistors is even greater. Therefore, keep the source resistance as low as possible. Other effects of high source resistances are decreased response speed and added pickup of extraneous voltages.

2-12. INPUT RESISTANCE. The Model 148 is a feedback amplifier, and its input resistance is obtained by using high feedback factors. When the source resistance exceeds its physical input resistance — the amplifier without feedback — the feedback is partially destroyed. Normally, do not exceed the maximum source resistance specified in Table 2; higher resistances may be used, but noise, offset, slow response time and instability may result. On the most sensitive ranges, the maximum source resistance is consistent with Johnson noise considerations.

2-13. SHIELDING.

a. Due to its narrow bandwidth, the Model 148 is somewhat insensitive to ac voltages superimposed upon a dc signal at the input terminals. However, ac voltages which are large compared with the dc signal may drive the Model 148 ac amplifier into saturation, erroneously producing a dc output at the demodulator. Therefore, shield the circuit to the Nanovoltmeter input, particularly for low-level sources.

b. Improper shielding can cause the Model 148 to react in one or more of the following ways:

1. Needle jitter or instability, from 10% to 20% of full scale.

2. High offset (dc bias). Changing the power cord polarity or the connection between the LO and GND terminals may affect the amount of offset.

3. Slow response time, sluggish action and/or inconsistent readings between ranges.

4. Amplifier saturation. Observe the wave form with an oscilloscope connected to the DEMODULATOR TEST Jack (Figure 3). With the input shorted, it should approximate the wave form shown in Figure 6. If excessive pick-up occurs, the wave form will resemble that of Figure 7. The circuit will operate reasonably well as long as the wave form is not clipped, as shown in Figure 8. At this point a dc offset is introduced.

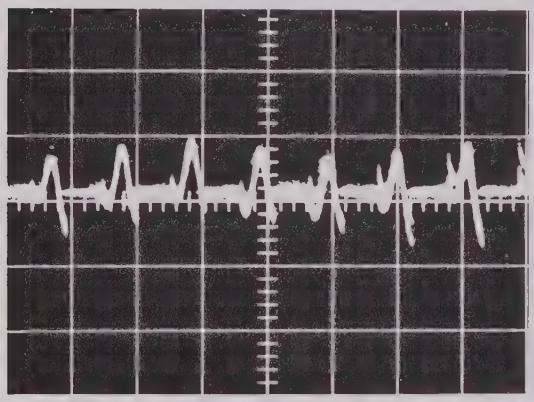


FIGURE 6. Normal Wave Form at Demodulator with Input Shorted. Scale is 0.1 v/cm vertical and 10 msec/cm horizontal.

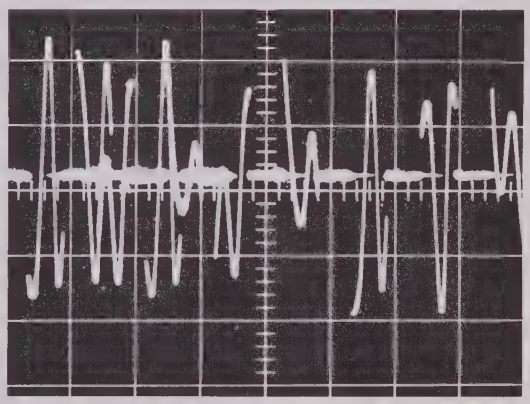


FIGURE 7. Wave Form at Demodulator Shown with Some Pickup. Measurements are adequate; there is no offset but some noise. Scale is 0.5 v/cm vertical and 10 msec/cm horizontal.

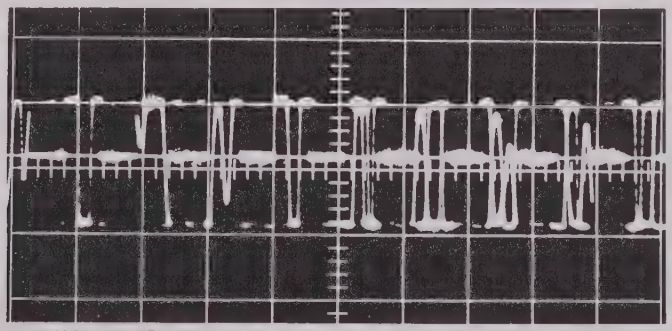


FIGURE 8. Wave Form at Demodulator when Amplifier is Saturated. Dc offset is introduced and there is greater noise. Note the Nanovoltmeter still reacts to the input signal. Scale is 5 v/cm vertical and 10 msec/cm horizontal.

c. To minimize pickup, keep the voltage source and the Nanovoltmeter away from ac sources. Shield as carefully as possible. Connect all shields together at the low side of the input or at the LO terminal. The voltage induced due to a magnetic flux is proportional to the area of the loop. Therefore, minimize loop areas in the shield connections as well as the input circuitry. Connect the shield at only one point. Run all wires in the circuit along the same path, so the loop area is only the small difference in position of two adjacent wires.

d. Stron third harmonic magnetic fields — 180 cps for 60-cps units — may create an 8-cps beat at the Nanovoltmeter output and meter. To reduce this effect, turn off all possible nearby sources, such as heavy-duty transformers. Remove the Model 148 and the measuring circuit as far as possible from the magnetic field. If removal does not greatly reduce the beat, magnetic as well as electrostatic shielding around the circuit may be necessary. For information concerning your particular shielding problem, contact Perfection Mica Corp., 1322 North Elston Street, Chicago, Illinois.

e. Shielding is preferable to input filters. Resistive-capacitive filters add noise (see Johnson noise equation), and the resistance value must be subtracted from the maximum source resistance in Table 2. Inductive-capacitive filters tend to create loop instabilities with the Nanovoltmeter. Capacity alone across the input, however, is less likely to cause loop instabilities, and it may be used to filter ac components in some cases.

2-14. THERMAL EMF'S.

a. Junctions between two dissimilar metals form a thermocouple and will develop an emf if there is a temperature difference between the metals. This effect may be seen by blowing on one junction and checking the meter indication.

b. Thermal emf's can cause the following problems:

1. Meter instability or zero offset much higher than expected. Note, though, the Model 148 can have some offset (paragraph 2-5).

2. Meter is very sensitive to ambient temperature differences. This is seen by touching the circuit, by putting a heat source near the circuit, or by a regular pattern of instability, corresponding to heating and air conditioning systems or changes in sunlight.

c. To minimize the drift caused by thermal emf's, use metals having the same thermoelectric powers in the input circuit. Gold, silver and low-thermal solder have a thermoelectric power within about ± 0.25 $\mu v/^{o}C$ of copper. This means a temperature unbalance of $1^{o}C$ between these metals would generate a thermal emf of about 0.25 microvolt. At the other extreme, germanium has a thermoelectric power of about 320 $\mu v/^{o}C$, and silicon will develop about 420 $\mu v/^{o}C$ against copper. Standard physical handbooks contain tables of thermoelectric powers of materials. Since the Model 148 input circuit is made of pure copper, use metals with nearly the same thermoelectric power. The best junction is copper to copper; however, slight amounts of copper oxide will cause a very slight thermal emf on the order of a few nanovolts per ^{o}C. The Model 1483 Kit contains all necessary equipment to make very low-thermal copper crimp joints.

d. Several other techniques will reduce the effects of thermal emf's. Use the zero suppression circuit to buckout constant voltages. Keep all circuits from open windows, fans, air conditioning vents and similar sources which vary temperatures. If connections must be soldered, use only cadmium-tin low-thermal solder, such as supplied in the Model 1483 Kit. Unlike metals — including regular solder — may be used and low thermal emf's obtained if a well-controlled oil bath or a good heat sink is used. Thermal voltages may be calculated from the thermoelectric power of the materials in the junction and the possible temperature difference between the junctions.

2-15. CIRCUIT CONNECTIONS.

a. When measuring in the microvolt and nanovolt regions, consider the effect the physical connections will have on the potential being measured. IR drops, which in most circuits are insignificant, now become important. For example, No. 20 AWG copper wire has a resistance of approximately 10 milliohms per foot. A 1-milliampere current through a 6-inch length of this wire will produce five microvolts. To reduce this drop to 0.5 nanovolt would mean using a wire 0.0006 inch long.

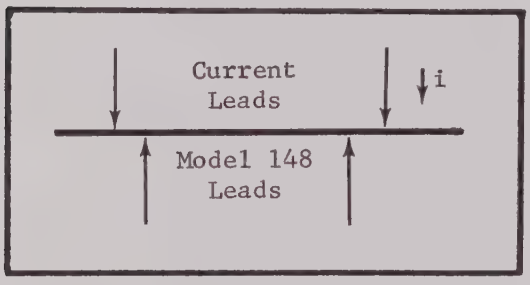


FIGURE 9. Using Model 148 with 4-Terminal Connections.

b. Four-terminal connections can often be used to eliminate this error. Refer to Figure 9.

c. If an unwanted IR drop is constant, the zero suppress may be used to nullify the voltage.

d. If the currents or resistances in the measuring system fluctuate, they will develop fluctuating voltages which will appear as noise or drift in the system.

2-16. OPERATING FROM SOURCE OTHER THAN 117 VOLT, 60 CPS.

a. If the ac power source is 234 volts, use a screwdriver to change the Line Voltage Switch on the back panel (Figure 3.) Change the fuse from 1/8 ampere to 1/16 ampere. Use only 250-volt MDL fuses. No other adjustment is necessary.

b. For 50-cps ac power sources, change the sideband filter capacitors, C103 and C104. The Model 148 can operate satisfactorily from 60 or 50-cps sources, but the best ac rejection is achieved when the filter is set for the line frequency. Use Keithley part C105-.109M (C103) and C45-.0155M (C104) for 50 cps. Refer to Figure 23 for component location.

2-17. RACK MOUNTING. (See Figure 10.)

a. The Model 148 is shipped for bench use with four feet and a tilt-bail. The Model 4002 Rack Mounting Kit converts the instrument to rack mounting to the standard EIA (RETMA) 19-inch width.

b. To convert the Model 148, remove the four screws at the bottom of each side of the instrument case. Lift off the top cover assembly with the

handles; save the four screws. To remove the feet and tilt bail from the bottom cover assembly, turn the two screws near the back. The two pawl-type fasteners will release the cover and allow it to drop off. Remove the feet and the tilt bail and replace the cover (2).

c. Attach the pair of rack angles (3) to the cabinet with the four screws (4) previously removed. Insert the top cover assembly (1) in place and fasten to the chassis with the two pawl-type fasteners at the rear. Store the top cover with handles, feet and tilt-bail for future use.

Item (See Fig. 10)	Description	Keithley Part No.	Quantity
1	Cover Assembly	17162C	1
2	Cover Assembly, Bottom (Supplied with Model 148)	17695B	1
3	Angle, Rack	14624B	2
4	Screw, Slotted, 10-32 UNC-2x1/4 (Supplied with Model 148)	---	4
5	Front Panel (Supplied with Model 148)	---	1

TABLE 5. Parts List for Model 4002 Rack Mounting Kit.

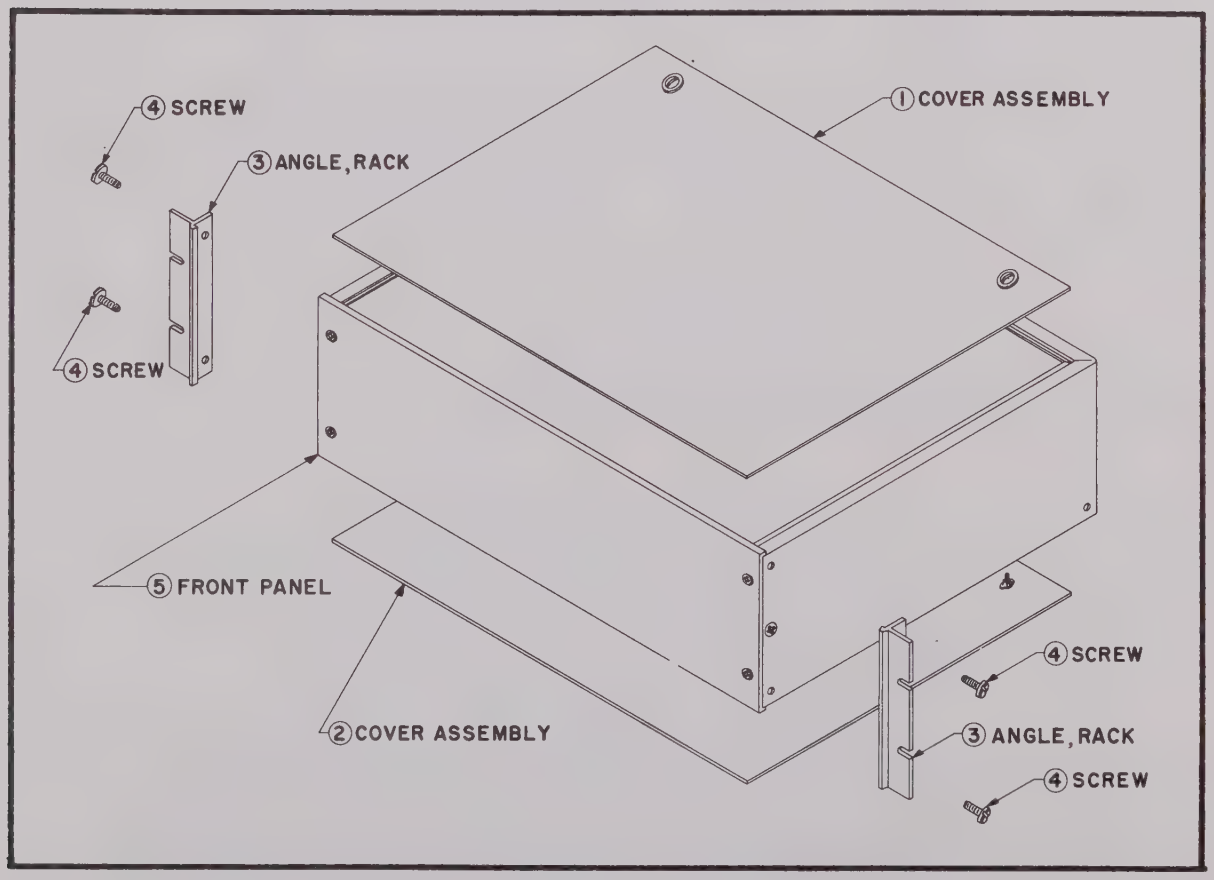


FIGURE 10. Exploded View for Rack Mounting.

SECTION 3. CIRCUIT DESCRIPTION

3-1. GENERAL.

a. The Model 148 consists of a chopper demodulator system followed by a dc amplifier. Feedback is applied to the whole loop. (See Figure 11.)

b. A mechanical chopper converts the dc input signal to a 94-cps signal. The ac signal is amplified, demodulated, dc amplified and applied to the meter. A feedback network samples the signal at the output and compares it to the input. The dc input signal and the feedback signal are compared in the input transformer primary. The transformer increases the voltage-difference signal between the two. The ac amplifier amplifies the difference signal; line-frequency sidebands of the 94-cps signal are filtered out. The ac signal is then demodulated by a saturated transistor switch and enters a dc amplifier, which has a feedback capacitor to filter out the demodulator ripple. The dc amplifier output is connected to the meter, the output terminals and the feedback network. The feedback resistors determine full-scale range. The zero suppress signal is connected to the feedback point in the input circuit.

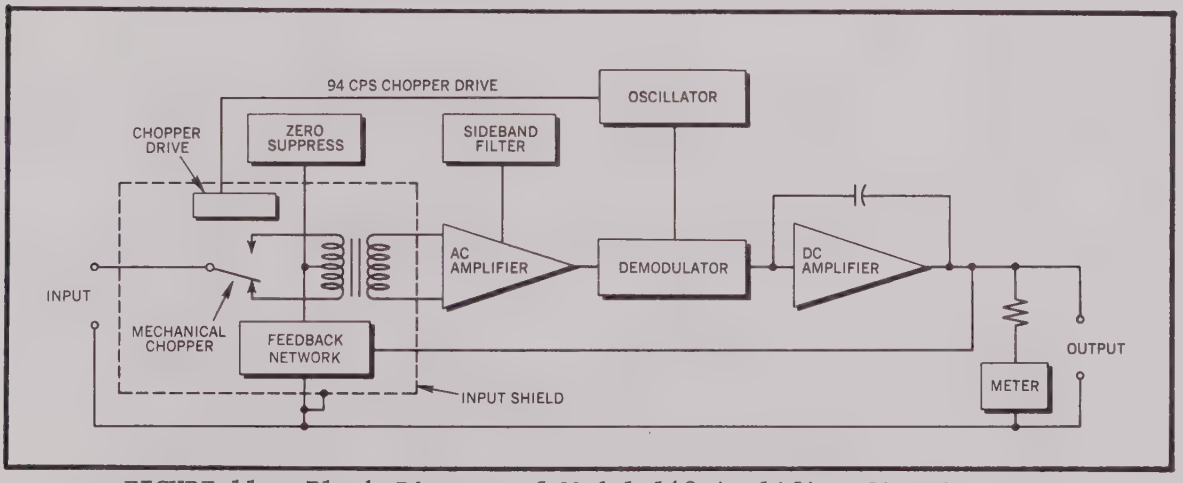


FIGURE 11. Block Diagram of Model 148 Amplifier Circuits.

c. The power source for the Model 148 is either line voltage or the rechargeable battery. Voltage from either source is applied to a dc-to-dc inverter and then to three highly regulated supplies. The three supplies furnish power to the oscillator and the amplifier circuits. There is also a battery charging circuit to charge the battery when it is necessary and when the line voltage is connected.

NOTE

The circuit designations referred to in this section are for Schematic Diagrams 17351F, 17352D and 17353D found at the back of the manual.

3-2. INPUT CIRCUIT.

a. The dc input signal is connected through the high terminal of the INPUT Receptacle, J101, to the center contact of the mechanical chopper, G101. (See Figure 12.) The feedback signal is applied to the center tap of the input transformer, T101. The chopper alternately applies a positive and a negative square-wave signal across each half of the primary. The magnitude of the square wave is proportional to the difference between the dc input and the feedback signals. T101 steps up this signal and applies it to the grid of tube V1.

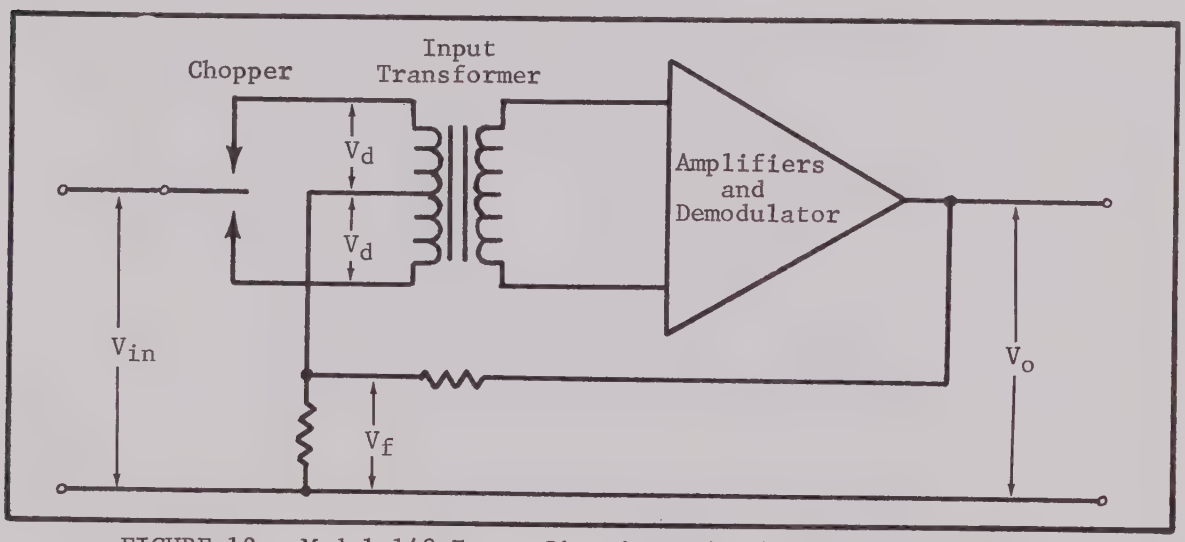


FIGURE 12. Model 148 Input Circuit. The dc input signal, V_{in}, is applied to the mechanical chopper. The feedback signal, V_f (the dc amplifier output voltage, V_o, times the feedback ratio, β), is applied to the transformer primary. The signal, V_d, stepped up by the transformer is the difference between the two, $V_d = V_{in} - V_f$. When the dc input signal is initially applied to the Model 148, V_f is zero and the voltage across the primary is entirely V_{in}. As the output voltage rises, V_f increases and V_d decreases to a small value. $V_f = V_{in}$, or $\beta V_o = V_{in}$. Only beta, which depends upon the RANGE and FUNCTION Switch settings, determines the amplifier gain.

b. The input compartment is designed to insure high thermal stability and to minimize internal ac pickup.

1. Thermal stability is obtained in part by using only copper wire in the input circuitry. The input transformer primary and the mechanical chopper leads are pure copper. The input connector is 99.5% copper; the impurities add to the mechanical strength without creating large thermal emf's. The low voltage portion of the FUNCTION Switch uses pure copper pins and rotor. All connections to components are made with pure copper crimp lugs. Connections between components are made by bolting the lugs together — not soldering — to reduce thermal emf's.

2. The input compartment is doubly shielded against magnetic and electrostatic pickup on all sides. The wires are physically placed to maintain minimum loop area, further minimizing pickup.

c. The feedback network is formed from the output of the dc amplifier back to the center tap of the primary of transformer T101. The RANGE Switch, S102, selects the feedback ratio used for each range.

3-3. AC AMPLIFIER.

a. The ac amplifier circuit amplifies the 94-cps difference signal which corresponds to the dc input signal. The signal is applied to the grid of V1 and further amplified by tube V2. A low-noise silicon transistor, Q3, provides a high impedance load for V2. The signal is then amplified by transistors Q4 and Q6. Potentiometer R109, between the Q3 emitter and Q4 base, adjusts the gain to compensate for beta variations. In addition, each stage has some local degeneration. Transistor Q5 is for impedance matching. The difference signal is amplified by transistors Q7 and Q8, which also form a full-wave signal for demodulation.

b. A series high-Q filter from the plate of V2 to circuit ground provides notch rejection at the power-line frequency sidebands. The values of capacitors C103 and C104 depend upon the power-line frequency. Due to the high Q of the inductor, the filter forms sharp notches at 34 cps and 154 cps for 60-cps power lines and 44 cps and 144 cps for 50-cps power lines. The ac amplifier's 94-cps gain and phase characteristics are affected very little.

c. The tube type and bias point of V1 are selected for low-noise operation at 94 cps. The high-Q tuned circuit in the plate of V1 has a good signal-to-noise ratio, and it provides a narrow bandwidth around 94 cps. The tuned circuit's Q is lowered on the higher ranges for amplifier stability.

3-4. DEMODULATOR. Q9 and Q10 in inverted configuration form a transistor switch demodulator. They convert the 94-cps wave from the ac amplifier into a dc voltage with ripple component. Resistors R123 and R124 sum the voltages from each to form a full-wave rectified signal. Jack J102 allows access to observe the waveform. The 94-cps oscillator furnishes a square-wave drive for the demodulator.

3-5. DC AMPLIFIER.

a. The demodulator signal is amplified by two low-drift, high-gain silicon transistors, Q11 and Q12, in differential configuration to compensate for temperature drift. Transistors Q13 and Q14 form the second amplifier stage. Total gain is about 500. The emitter follower output stage — transistors Q15 and Q16 in pnp-npn configuration — draws little current at zero output. Diodes D101 and D102 limit the output current, protecting Q15 and Q16.

b. A feedback loop with capacitor C115 around the dc amplifier acts as an integrator, filtering the ripple component of the demodulated waveform. The effective capacity, which is approximately the value of C115 times the dc amplifier gain, and the feedback factor (or open-loop gain) determine the response speed of the system. The capacitive feedback also lessens the noise in the amplifier outside the system bandpass.

3-6. OSCILLATOR. The oscillator circuit, stable to 0.1 cps, has three parts: phase-shift network for a 94-cps signal, an amplifier to drive the chopper, and a transistor switch and phase compensation network for the square-wave demodulator drive.

a. The phase-shift network consists of capacitors C301 through C303, resistors R319 through R321, and the combined resistance of R303 and R318, which bias transistor Q17. The input impedance of the emitter follower, Q17, has little loading effect on the effective value of this last resistance. Transistor Q18 compensates for signal losses in the phase-shift network. Potentiometer R319 adjusts the signal frequency. Resistor R322, the filament of a low-power subminiature tube, Raytheon CK6418, provides variable degeneration to maintain a sine wave output to the next stage.

b. From the phase-shift network, the signal is amplified and used to drive the chopper. Transistor Q19 matches the impedance of transistor Q20 to the phase-shift network. Potentiometer R313 adjusts the signal amplitude. From transistor Q20, the signal is applied to the primary of transformer T301, which drives the class B stage, transistors Q22 and Q23. After amplification the sine-wave signal is applied to the mechanical chopper, G101. Transistor Q21 develops the bias voltage for the class B stage, providing ambient temperature compensation for the chopper-drive signal amplitude. The center taps of transformers T301 and T302 supply dc current for the class B stage.

c. The chopper drive signal is also applied to the primary of transformer T302. The transformer drives transistors Q24 and Q25 through a phase-compensating network, resistors R308 to R310, R323 and capacitor C309, which compensates for the chopper phase shift. The transistors alternate between saturation and cut off to form a square-wave drive for the demodulator, transistors Q9 and Q10.

3-7. ZERO SUPPRESSION. The zero suppress circuit provides a regulated voltage from the power supplies to buckout steady background potentials in the input signal. The 10-turn FINE Control, potentiometer R168, is connected between -12 and +12 volt outputs. The resistors R165 to R167 and R172 in the COARSE Switch, S103, further divide the voltage. When the FUNCTION Switch, S101, is in the MILLIVOLTS position, the suppress voltage is applied directly to the primary of transformer T101. When the FUNCTION Switch is in MICROVOLTS position, the suppress voltage is divided by an evenohm, 0.25% resistor, R140, copper resistor R137A, and a copper resistor R141. Using copper resistors for the lowest voltage points shunted by evenohm resistors provides thermal and resistive stability.

3-8. POWER SUPPLIES (See Figure 13.) The power supply for the Model 148 is powered by an unregulated supply from the line voltage or rechargeable battery. Either source feeds a dc-to-dc inverter and three highly regulated supplies with outputs of +12, -12, and +1.2 volts. These power all the other Model 148 circuits.

a. The line voltage, battery and battery charging circuit are controlled through the POWER SUPPLY Switch, S201. When the switch is in AC, the battery is charged if necessary and the power supply uses line voltage. When the switch is in OFF, the battery charging circuit will operate if necessary; all other circuits are off. When the switch is in BATTERY, the power supply uses the battery; the other two circuits can not operate.

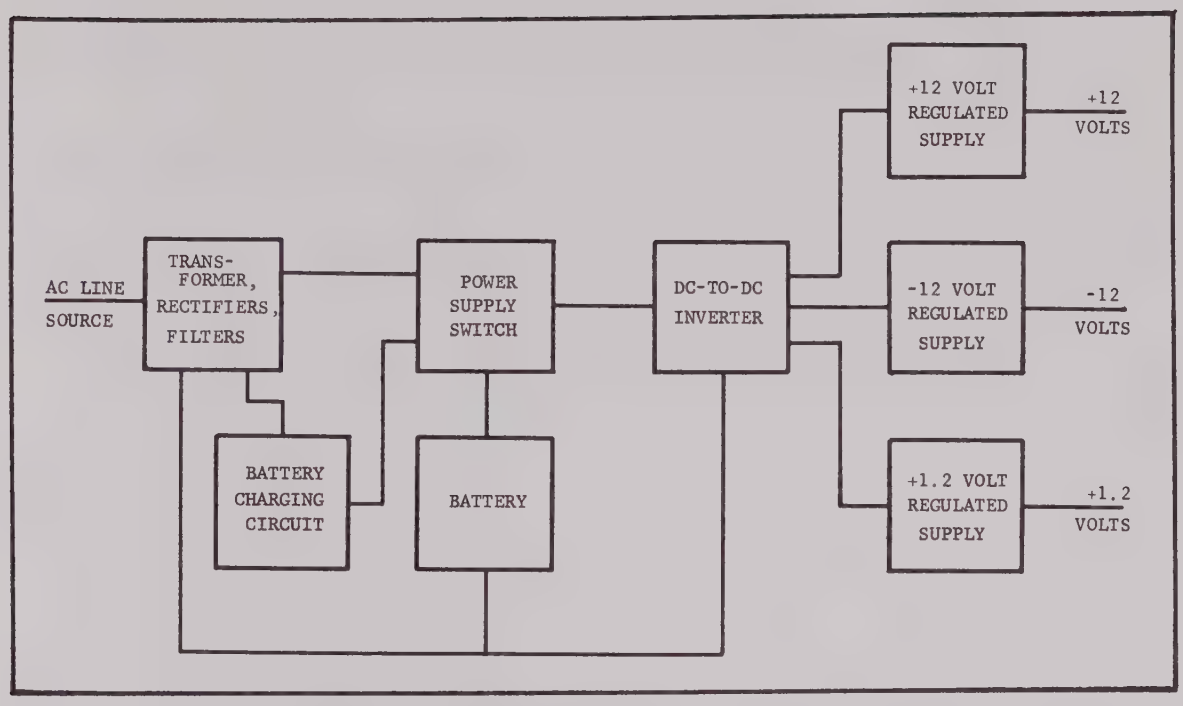


FIGURE 13. Block Diagram of Model 148 Power Supplies.

b. The unregulated supply consists of a full-wave rectifier, diodes D212 and D213, and a dropping resistor, R232. The AC CONNECTED Lamp, DS201, is in series with resistor R226, which is connected directly across this supply. For battery operation the primary of transformer T201 is disconnected.

c. Voltage from the unregulated supply or the battery is applied to the dc-to-dc inverter circuit. Transistors Q28 and Q29 form a switching network to supply an interrupted voltage to transformer T202. The switching frequency is about 2 kc, well away from the carrier frequency. Transformer T202 has a saturable ferrite core. The inverter circuit supplies voltages to the three regulated supplies, which are basically the same series regulator design.

d. For the +12 volt supply, diodes D206 and D207 full-wave rectify the signal from transformer T202. The signal is applied to the pass transistor, Q30. The output of Q30 is divided by resistors R208 and R209 and compared to the zener diode reference, D205. Transistors Q34 and Q33 amplify any potential difference and apply a signal to the base of transistor Q32. Diodes D204 and D205 fix the emitter voltage of Q32; therefore, the collector voltage of Q33 directly determines the current through Q32, which comes from the -12 volt supply. The current drop through resistor R216 determines the voltage at the base of transistor Q31, and therefore the output voltage through the base-emitter junction. Diode D203 limits

the base-to-emitter voltage of the Q30 and Q31 combination, thus also limiting the current which it will pass. Diode D203 protects the pass transistor, Q30, if output of the supply is shorted.

e. For the -12 volt regulated supply, diodes D210 and D211 full-wave rectify the signal from transformer T202. The signal is applied to the pass transistor, Q35. The output of Q35 is divided by resistors R217 and R218, thereby comparing it to the +12 volt supply, using ground as a reference. Transistors Q38 and Q39 amplify any potential difference and apply a signal to transistor Q37. Transistors Q35 and Q36 form a Darlington combination, and work similarly to that in the +12 volt supply. The differences are that the -12 volt supply draws a higher current than the +12 volt supply, and therefore uses two diodes, D208 and D209, to protect the pass transistor. The negative "bootstrap" current supply is from a filter, resistor R225 and capacitor C210.

f. The +1.2 volt supply operates in the same manner as the +12 volt supply with these differences. The output of the pass transistor, Q40, is compared to the output of the +12 volt supply divided down one tenth. The operating voltages for the comparator stage, Q43 and Q44, are obtained from the +12 and -12 volt supplies. Except for the comparator stage, npn transistors are used.

3-9. BATTERY CHARGING CIRCUIT.

a. The battery charging circuit operates when the POWER SUPPLY Switch, S201, is in AC or OFF position, and only when the battery needs charging.

b. The battery voltage is compared to a reference by two cascaded transistors, Q26 and Q27. When it is low, a charging current from transformer T201 is applied to the battery through the BATTERY CHARGING Lamp, DS202, transistor Q27 and diode D216. The reference is zener diode D214; the reference voltage is adjusted by potentiometer R228. The difference between the battery and the reference potentials determines the magnitude of the charge current through Q27. A silicon diode, D216, prevents the battery from being run down because of leakage currents through Q27, a germanium power transistor. Diode D215 limits the base-to-emitter voltage of the Q26 and Q27 combination, so no more than 400 milliamperes (the rated maximum charge current of the battery) can flow in the circuit.

c. This circuit protects the battery. It decreases the charging current to a trickle-charge rate as the battery terminal voltage approaches the reference voltage. It also limits the charge current if the battery was used beyond its ampere-hour capacity. Note, however, that the battery can be damaged if it is used far beyond its capacity. A polarity reversal of a cell may occur, causing heavy circulating currents within the battery.

SECTION 4. MAINTENANCE

4-1. GENERAL.

a. Section 4 contains the maintenance, troubleshooting and calibration procedures for the Model 148. It is recommended these procedures be followed as closely as possible to maintain the instrument's specifications.

b. The Model 148 requires no periodic maintenance beyond the normal care required of high-quality electronic equipment. Components operate well below maximum ratings. Principal maintenance is an occasional chopper replacement. (See paragraph 4-3.) Occasional verification of meter calibration should show any need for adjustment.

4-2. PARTS REPLACEMENT.

a. The Replaceable Parts List in Section 5 describes the electrical components of the Nanovoltmeter. Replace components only as necessary, and use only reliable replacements which meet the specifications. The Model 148 uses no special critical parts except for resistor R322, which is a subminiature tube filament, and the components listed in Table 6. Make sure parts coded 80164 in the Replaceable Parts List are purchased only from Keithley Instruments or its distributors.

b. The physical location of components in the input compartment is critical. Place replacement parts in the exact position shown in Figure 14. Circuit loops will introduce extraneous ac signals; see paragraph 2-13. The order of the copper lugs on the insulated posts greatly affects offset and noise in the Model 148. Tag or record the number on each lead as it is removed. Replace in reverse sequence. Table 6 lists components which have lugs crimped on them. When replacing these parts, clean the lug with a non-metallic abrasive, such as Scotch-Brite found in the Model 1483 Kit, or its equivalent. Follow the procedures necessary for good low-thermal connections.

Component	Circuit Desig.	Keithley Part No.
Battery pack assembly	BA201	Model 1489
Mechanical chopper assembly (See paragraph 4-3.)	G101	17689A
Input connector assembly	J101	17638A
Copper feedback resistor assembly	R137	17627A
Evanohm resistor assembly	R139	17635A
Evanohm resistor assembly	R140	17636A
Evanohm resistor assembly	R141	17637A
Function switch plate assembly	S101	16883A
Input transformer assembly	T101	17623B

TABLE 6. Model 148 Pre-assembled Components. These parts have lugs crimped on them and the proper lead length. Use only Keithley parts for replacements; follow instructions given in paragraph 4-2.

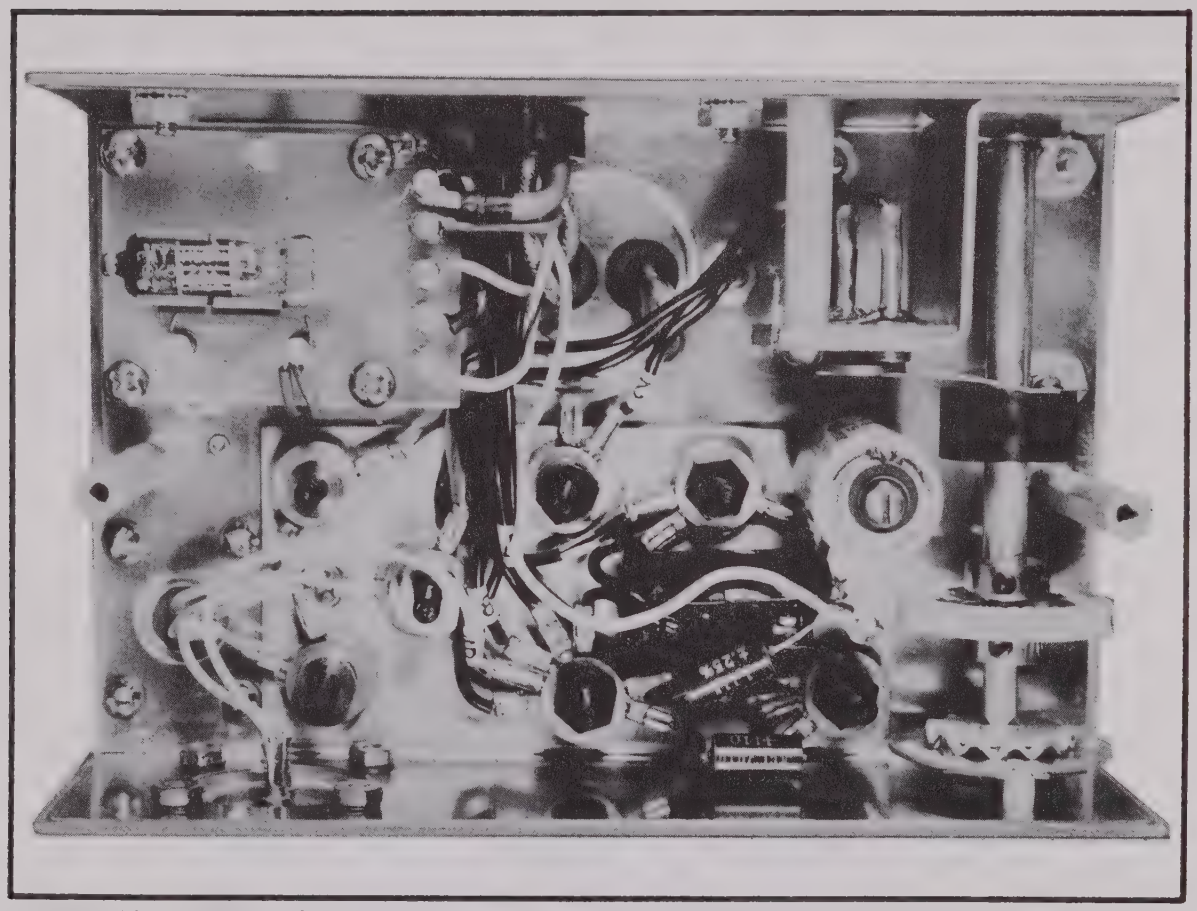


FIGURE 14. Model 148 Input Compartment. Note exact physical location of parts. If replacing, duplicate location and order of leads on posts. Figure 21 gives circuit designations.

4-3. MECHANICAL CHOPPER REPLACEMENTS.

a. The mechanical chopper is designed for long life. However, since it is mechanical, it will eventually wear and become noisy. At this point, replacement is necessary.

b. Removal Procedures.

1. Disconnect the chopper drive coil at connector J302 (Figure 20). Carefully remove the three thumb screws in the input compartment and the three chopper lead lugs.

2. Carefully slide the degaussing coil, L302 (Figure 20), from the chopper body; remove the old chopper.

c. Replacement Procedures.

1. Slide the degaussing coil, L302, over the new chopper body from the bottom. Orient so that the cut-out in the coil fits over the chopper drive lead.

2. Mount the chopper and coil in the input compartment. Dress leads as shown in Figure 14.

3. Check the instrument for proper operation. Follow paragraph 4-9, subparagraph b, steps 1, 2 and 3.

d. Degaussing Coil Adjustment Procedures.

1. With the input shorted, use the ZERO SUPPRESS Controls to generate a signal through the Model 148. Use a differential input to the Type 503 Oscilloscope (+ and - inputs) to observe the wave form between the collectors of transistors Q9 and Q10 (Points P and Q, Figure 25).

2. The wave form amplitude varies as the degaussing coil is moved along the chopper body. Potentiometer R301 (Figure 21) determines the effect of the coil on the wave form. Adjust both the coil and the potentiometer for minimum amplitude. Reverse the red and black leads to the degaussing coil if necessary.

3. An 8-cps beat at points P and Q may be present. Use battery operation to reduce the beat; refer to paragraph 2-3.

4-4. TROUBLESHOOTING.

a. The following procedures give instructions for repairing troubles which might occur in the Model 148. Use these procedures to troubleshoot and use only specified replacement parts. Table 7 lists equipment recommended for troubleshooting. If the trouble cannot be readily located or repaired, contact Keithley Instruments or its representatives. Paragraph 2-17 describes how to remove the Nanovoltmeter cover.

b. Paragraphs 4-6, 4-7 and 4-8 give step-by-step procedures for troubleshooting and checking out the power supply, oscillator and amplifier circuits. Follow these in the order given. Tables 9, 10 and 12 are troubleshooting tables for these circuits. Also refer to Section 3 to find the more crucial components and to determine their function. The Schematic Diagrams, 17351F, 17352D and 17353D, contain the voltages at certain points in the circuit.

NOTE

Before troubleshooting inside the Model 148, check the external circuits (paragraph 4-5). Always check out the power supply and the oscillator circuits before touching the amplifier circuits. The amplifier circuits often appear faulty only because of a defect in the power supply or oscillator circuits.

4-5. PRELIMINARY TROUBLESHOOTING PROCEDURES.

a. Before troubleshooting, check the outside circuits to the Model 148. Isolate the Nanovoltmeter from all external effects:

1. Disconnect all outside circuits from the INPUT and OUTPUT Receptacles, and GND and LO terminals.

Instrument	Use
Hewlett-Packard Model 5512A Electronic Counter, 300-kc counting rate, ±0.1% accuracy.	Monitor oscillator frequency.
Keithley Model 662 Guarded DC Differential Voltmeter	Check voltage at output terminals.
RCA Model WV98B Senior Voltohmyst, 11 MΩ input resistance, ±3% accuracy, 0 to 1500 volts dc.	Check dc voltages throughout circuits.
Tektronix Type 503 Oscilloscope, dc to 450 kc.	Check wave forms for troubleshooting and calibrating.

TABLE 7. Equipment Recommended for Troubleshooting and Calibrating the Model 148. Use these instruments or their equivalents.

2. Connect a low-thermal short across the INPUT Receptacle. The best connector is a Model 1486 male low-thermal connector with a short length of pure copper No. 18 or No. 20 wire crimped between the two pins. The next best is a Model 1481 Low-Thermal Input Cable with the clips connected together. Keep the cable as far as possible from ac sources, and avoid a loop where the alligator clips are connected.

3. Set the ZERO SUPPRESS COARSE Control to OFF.

b. If battery operation is trouble free, set the POWER SUPPLY Switch to BATTERY. Disconnect the power cord from the power line. Battery operation eliminates many ground-loop connection problems with the test equipment.

c. If ac operation is used, check the Line Voltage Switch for correct position and the Fuse for correct rating.

NOTE

Often, after checking out according to paragraph 4-5, the Model 148 will function normally. This points to problems in the circuits outside the Nanovoltmeter. Refer to Table 4 to check the external circuit.

4-6. CHECK OUT AND CALIBRATION PROCEDURES.

a. The following procedures give the steps to check out and calibrate the Model 148 circuits. If a circuit fails to check out at any point, refer to the circuit's troubleshooting table. Continue as long as the points check out. Use the equipment listed in Table 7.

b. Procedures are given for the power supply, oscillator and amplifier circuits. These cover the principal adjustments to bring the instrument within specifications.

c. If the Model 148 is not within specifications after performing these checks and calibrations, return the unit to Keithley Instruments for further checkout, or follow the troubleshooting procedures to find the fault.

NOTE

Make sure the power supply and oscillator circuits are operating correctly before checking the amplifiers. All circuits depend upon properly functioning power supplies. If taken out of order, the resulting adjustment may be faulty.

4-7. POWER SUPPLY CHECK OUT AND CALIBRATION.

a. All circuits depend upon the power supplies. Therefore, the +12, -12 and +1.2 volt outputs must be operating correctly before further checks are made. If the power supply fails to check out at any point, refer to Table 9. After clearing the trouble, continue the check.

b. Procedures for Checking Regulated Power Supplies.

1. Connect the low-thermal shorting plug to the INPUT. Set the Model 148 controls as follows:

POWER SUPPLY Switch	OFF
RANGE Switch	100
FUNCTION Switch	MILLIVOLTS
ZERO SUPPRESS COARSE Control	OFF
Line Voltage Switch	Set to line voltage

2. Plug in the power cord. The AC CONNECTED Lamp should light.

3. Measure the voltage at the Yellow-White wire on the POWER SUPPLY Switch front deck (Point A, Figure 20). It should be -18 volts dc ±2 vdc.

4. Turn the POWER SUPPLY Switch to AC. Use the oscilloscope to check the wave form at point E (Figure 26) in the dc-to-dc inverter. Wave form should resemble that in Figure 15.

5. Measure the signal levels and ripple with respect to low of the three regulated supplies. Table 8 gives the values.

Regulated Power Supply	Test Point, Figure 21	Signal Level, Volts dc	Maximum Ripple, Millivolts Peak-to-Peak	Resistance to Ground, Ohms
+12 volt	B	11.6 to 12.8	0.3	850 ±100
-12 volt	C	11.9 to 13.1	2.0	460 ± 70
+1.2 volt	D	1.16 to 1.28	0.2	20 ± 3

TABLE 8. Signal Level, Maximum Ripple and Resistance for Regulated Power Supplies.

TROUBLE	PROBABLE CAUSE	SOLUTION
No voltage at point A (Fig. 20)	Blown fuse.	Check for shorted transformer T201 or wiring; then replace fuse.
	D212, D213 or R232 open.	Check components; replace if faulty.
Irregular wave form at point E (Fig. 26)	Overloaded regulators	Check resistances at power supply test points. (See Table 8.)
	Defective Q28 and/or Q29	Check components; replace if faulty.
Incorrect voltage at points B, C and D (Fig. 21)	Defective D205, Q33, Q34, Q38 (or Q39), D204, D212	Check components; replace if faulty.
Incorrect voltage only at point D (Fig. 21)	Shorted V1 or V2 filaments	Check V1 and V2 filament.
	Defective Q43 or Q44	Check components; replace if faulty.
High ripple at points B, C and D (Fig. 21)	Defective oscillator	See paragraph 4-8.
	Defective D204, D212, D205, Q33, Q34, Q38 or Q39.	Check components; replace if faulty.
High ripple only at point D (Fig. 21)	Defective Q43 and/or Q44.	Check components; replace if faulty.
Unable to adjust for -8.1v at point G (Fig. 26)	Defective D214, R227, R228, R229 or Q26.	Check components; replace if faulty.
High ripple at B, C and D (Fig. 21) on battery operation only.	Low battery voltage.	Charge battery (paragraph 2-4).

TABLE 9. Troubleshooting Table for Power Supply and Battery Charging Circuits.

c. Procedures for Charger Circuit.

1. Disconnect the battery pack; do not let the terminals touch the chassis. Connect the Nanovoltmeter to the ac power line. Put the POWER SUPPLY Switch in AC position.

2. Set the charger bias voltage to -8.1 volts dc at point G, Figure 26. Adjust potentiometer R228 (Figure 27) for this value.

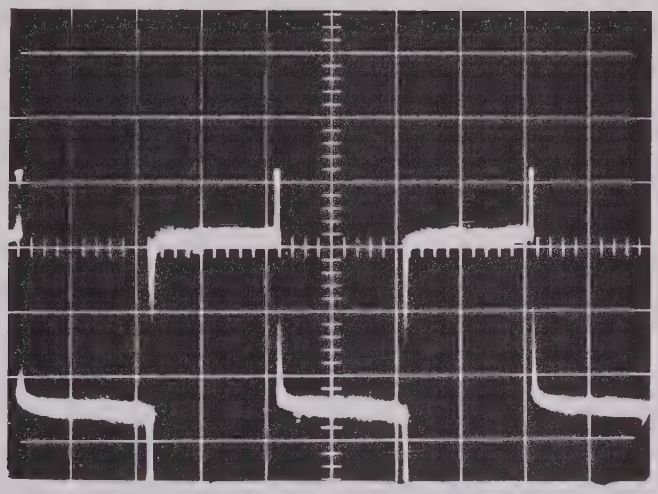


FIGURE 15. Correct Wave Form in dc-to-dc Inverter. Point E, Figure 26, was monitored. Scale is 5 v/cm vertical, 0.2 msec/cm horizontal.

3. Connect the battery; make sure the polarity is correct (red to red). The positive side of the battery is ground. The BATTERY CHARGING Lamp should light, showing the charging circuits work. The lamp brightness directly indicates the charge current — the brighter the light, the greater the current.

4. After connecting the battery pack, the bias voltage may change. This is normal and no readjustment is required.

4-8. OSCILLATOR CHECK OUT AND CALIBRATION.

a. The oscillator circuit drives the demodulator and the chopper. If the power supplies check out, continue on the oscillator. If the oscillator fails to check out at any point, refer to Table 10. After clearing the trouble, continue to check.

b. Procedures.

1. Connect the Type 503 Oscilloscope and the Model 5512A Electronic Counter to point F (Figure 21).

2. Set the oscillator frequency to 94 cps ±0.1 cps with potentiometer R319 (Figure 28).

3. Set the oscillator signal amplitude to 15.4 volts peak-to-peak ±0.2 v peak-to-peak, measured on the oscilloscope. Adjust with potentiometer R313 (Figure 28).

4. Check the wave form at point F. It should be essentially sinusoidal, as in Figure 16.

NOTE

If transistors Q21, Q22 or Q23 are replaced, it may be necessary to change resistor R307. A 27-kilohm resistor should provide the proper bias for Q22 and Q23. The wave form at point F should resemble Figure 16. If it does not but resembles Figure 17, use a 15-kilohm resistor for R307.

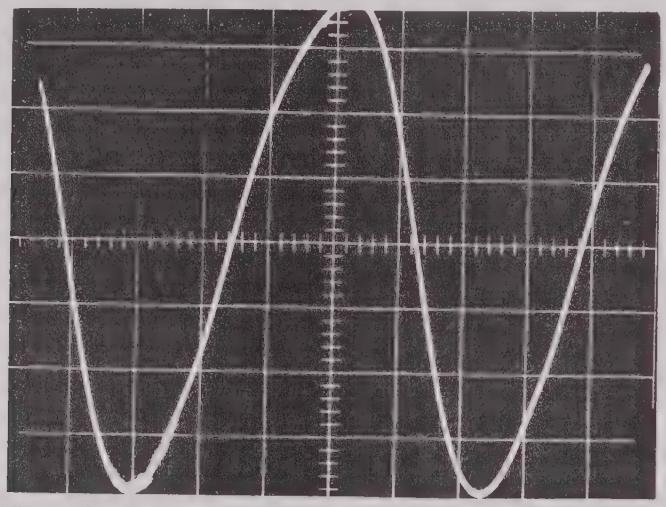


FIGURE 16. Correct Wave Form at Point F (Figure 21) in Oscillator Circuit. Scale is 2 v/cm vertical, 2 msec/cm horizontal.

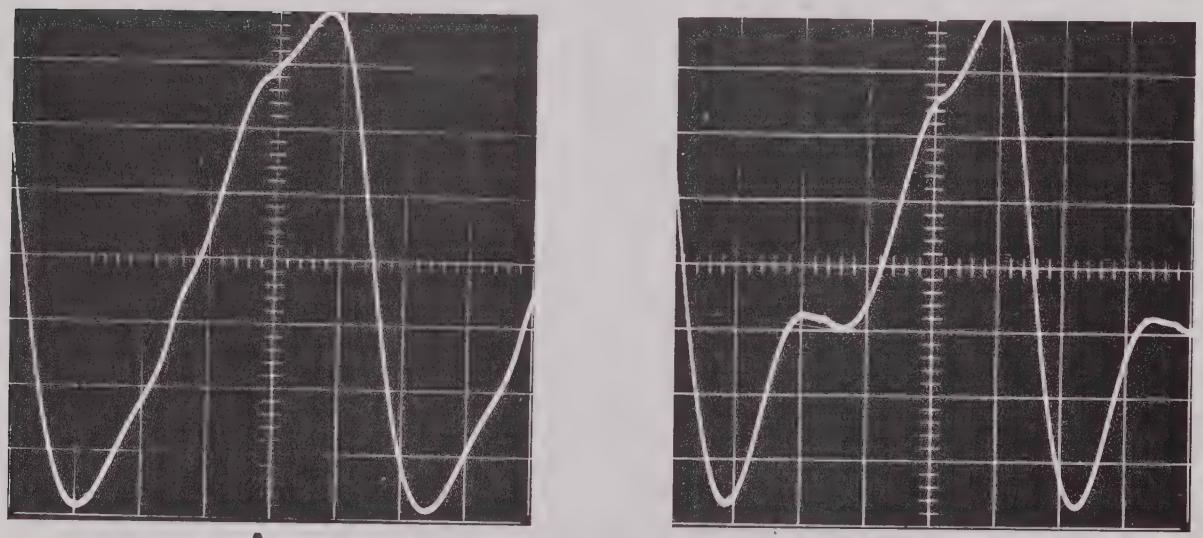


FIGURE 17. Improper Wave Forms at Point F (Figure 21) in Oscillator Circuit. Wave A indicates the wrong bias; wave B is distorted. Scale for both is 2 v/cm vertical, 2 msec/cm horizontal.

TROUBLE	PROBABLE CAUSE	SOLUTION
Unable to adjust frequency to 94 cps	Shorted chopper drive circuit	Disconnect chopper at J302. Check for 94 cps at Q19 emitter (Point H, Figure 28). Check for shorted wiring and chopper coil.
Distorted, off-frequency wave form at point H with chopper disconnected	Defective Q17, Q18 or Q19	Voltage at point H should be 1 to 2 volts peak-to-peak, sine wave. If not, check components; replace if faulty.
Low voltage, distorted wave form at point F	Defective Q17, Q18, Q19 or R322 (Fig. 17b)	Check components; replace if faulty.
	Defective Q20, Q21, Q22, Q23 or R313 (Fig. 17 a or b)	Check the voltages, Q20 to Q23, given on schematic 17353D. Replace faulty components.
	Improper bias to Q22 and Q23 (Fig. 17a)	Adjust R307 as in note.
Unstable frequency.	Defective Q17, R319, C301, C302, C303 or R321, R320, R303, R318	Check components; replace if faulty. Q17 or R319 are most likely parts.

TABLE 10. Oscillator Circuit Troubleshooting Table.

4-9. AMPLIFIER CHECK OUT AND CALIBRATION.

a. The check out and calibration of the amplifier circuits is divided into two parts: operational check and gain calibration. The operational check does not have to be followed by gain calibration. Use this to check the Model 148 operation. If the amplifiers fail to check out at any point, refer to Table 12. After clearing the trouble, continue the check.

NOTE

Check the power supply and oscillator circuits before adjusting the amplifiers. If the other two circuits are changed, the amplifier circuit may need recalibration.

b. Operational Check Procedures.

1. Connect the low-thermal shorting plug to the INPUT. Set the front panel controls as follows:

POWER SUPPLY Switch	BATTERY
RANGE Switch	0.3
FUNCTION Switch	MICROVOLTS
ZERO SUPPRESS COARSE Control	OFF
ZERO SUPPRESS FINE Control	At one end of rotation

2. On the 0.3-microvolt range, the meter offset should be less than 0.2 microvolt (66% of full scale). It may be higher if the shorting plug is not used.

3. Switch the ZERO SUPPRESS COARSE Control to 1; the meter should shift 0.2 to 0.16 microvolt.

4. Connect the Type 503 Oscilloscope to the Model 148 OUTPUT. Set the oscilloscope amplifier to dc coupling, 0.2 volt/cm, time base to 0.1 or 0.2 second/cm. Set the Model 148 to the 0.1-microvolt range. Set the ZERO SUPPRESS COARSE Control to 1 to obtain a 0.1-microvolt signal. The response time (from 10% to 90% of final value) should be between 0.2 and 0.4 second. Adjust potentiometer R109 (Figure 25) for this value.

NOTE

Potentiometer R109 is a critical control. It adjusts the amplifier gain which affects output ripple, input resistance and maximum source resistance as well as response time. Adjust this control only if one of these characteristics is slightly out of specifications.

c. To properly calibrate the Model 148 amplifier gain, an accurate microvolt-millivolt source is necessary. The value of this calibration depends very much on the source. If one is not available, it is recommended that the gain be calibrated by Keithley Instruments. If a source should be constructed, here are some guides.

1. Use good low-thermal construction techniques (paragraph 2-10 and following).

2. The source accuracy is determined by the accuracies of the divider and the power supply.

3. Divide the source to the microvolt level with an accurate low-thermal divider. Keithley Part R107 is a good low-level copper resistor with good low-thermal performance. Its 1000:1 ratio is accurate to better than 0.5%. Use standard ratio techniques to measure the exact ratio. If the R107 is used, shunt it with about an 100-ohm evanohm resistor. This reduces temperature dependance of the divider to about 60 ppm/°C, from the resistance temperature coefficient of copper of about 4000 ppm/°C.

d. Gain Calibration Procedures.

1. Connect the microvolt source to the Model 148 INPUT.

2. Connect the Model 662 Differential Voltmeter to the Model 148 OUTPUT Receptacle.

3. Before applying power to the microvolt source, adjust the ZERO SUPPRESS Controls for zero output at the output terminals.

4. For a given full-scale input signal, measure the output voltage. It should be 1 volt dc ±1% for all ranges.

5. Check the resistors in the RANGE Switch by following the ranges in Table 11. If these ranges check out, all ranges are within specifications. If a range fails to check, refer to Table 12. Rezero using the Zero Suppress Control before each check.

6. After calibrating the amplifier, adjust the input voltage (or zero suppression) for full-scale outputs as shown on the differential voltmeter, on any range from 1 microvolt and above. Adjust potentiometer R136 (Figure 25) for exactly full-scale meter deflection.

4-10. AMPLIFIER PHASE CHECK. Connect the oscilloscope to DEMODULATOR TEST Jack on the rear panel. Turn the ZERO SUPPRESS COARSE Control to 3; turn the FINE Control away from the end point until the oscilloscope indicates that the amplifier is not saturated (the wave form is not clipped at either end). The wave form should appear as a half-wave rectified sine wave, positive or negative. See Figure 18. It should not appear out of phase as in Figure 19. Low frequency modulation and some bounce off the envelope of the signal is normal.

Range	Resistor Used In RANGE Switch
100 Millivolts and all other ranges	R137B, R139, R144
0.01 and 0.1 millivolt	R149, R150
0.1 Millivolt	R170
0.3 Millivolt	R171
1 Millivolt	R145
3 Millivolts	R146
10 Millivolts	R147
30 Millivolts	R148
100 Millivolts and 100 Microvolts	R137 ratio

TABLE 11. Range Checkout. If these ranges are correct, all Model 148 ranges are correct. If any fail, check the listed resistor.

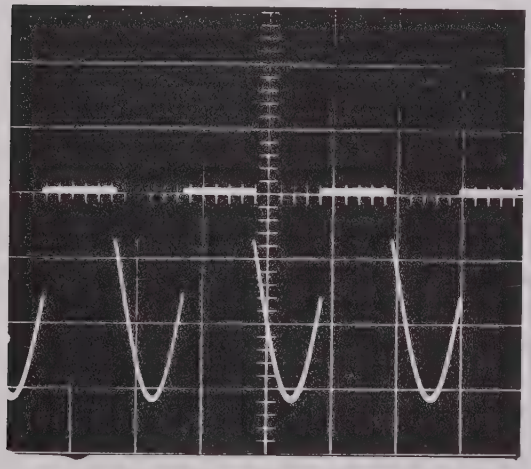


FIGURE 18. Correct Wave Form at DEMODULATOR TEST Jack. See paragraph 4-10. Scale is 1 v/cm vertical, 5 msec/cm horizontal.

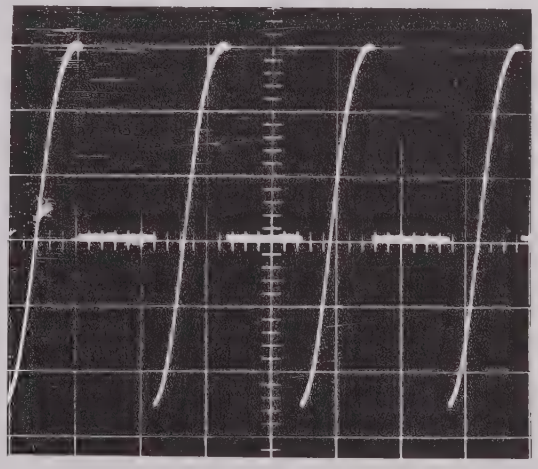


FIGURE 19. Out-of-Phase Wave Form at DEMODULATOR TEST Jack. See paragraph 4-10. Scale is 1 v/cm vertical, 5 msec/cm horizontal.

TROUBLE	PROBABLE CAUSE	SOLUTION
High zero offset	Short in feedback network.	Make sure lugs do not touch each other or the copper plate in input compartment. Check resistances.
	Maladjusted degaussing coil.	Adjust (paragraph 4-3).
Random zero drift, tens of nanovolts or more; sometimes reduced if the cabinet slapped. Response speed is good.	Noisy chopper	Replace chopper; see paragraph 4-3.
Zero drift greatly affected by slight movement of FUNCTION Switch within a setting.	Maladjusted or dirty FUNCTION Switch.	Loosen set screws on rotor hub (Figure); slide rotor away from pins. Clean rotor and pins with non-metallic abrasive. Adjust such that the rotor is flush with and makes contact with all three pins consecutively, two at a time.
Zero drift very temperature sensitive.	Contaminated INPUT Receptacle, shorting plug, or connection in input compartment.	Clean INPUT Receptacle with non-metallic abrasive. If contamination goes below plated surface, replace connector. Clean lugs with non-metallic abrasive; be sure to return to posts in original order.
Response speed very slow, possibly offset also high. Cannot adjust to specifications with R109.	Low ac amplifier gain, due to bad active element.	Set to 0.1-microvolt range, ZERO SUPPRESS COARSE to 3, FINE to an easily readable signal. With oscilloscope, check for square wave at V1, grid, and sine wave at input and output of each succeeding stage. Check dc voltages, V1 through Q8, given on schematic 17351F. Replace faulty components.
	Improper amplifier phasing	See paragraph 4-10. If it is incorrect, use lissajous patterns to check phase from grid V1 through each stage to base Q7. Shifts of up to about 30° are acceptable. Check capacitors and active elements.

TABLE 12 (Sheet 1). Amplifier Troubleshooting Table.

TROUBLE	PROBABLE CAUSE	SOLUTION
Response speed very slow, possibly offset also high. Cannot adjust to specifications with R109.	Low gain in dc amplifier.	Unsolder and lift one end of R123 and R124. See points M and N, Figure 25. Apply 10 to 100mv to base of Q11 to zero meter. Change input by 1 millivolt; output should shift 0.3 to 3.0 volts. If not or if more than 100mv is required to zero, check transistors, beginning with Q11 and Q12. Q11 and Q12 are matched for offset. Replace only with parts purchased from Keithley.
	Leaky or shorted C115.	Check; replace if faulty.
Demodulator does not "clamp" during one-half cycle (Figure 18).	Defective Q9, Q10, Q24 or Q25.	Check for sine wave at secondary of T302, square wave at collector Q24 and Q25 and base Q9 and Q10. Replace faulty components.
Greater than 20-mv peak-to-peak ripple at output terminals on ac power. On battery operation, output ripple is above 5 mv p-p.	Instrument located near high 180-cps magnetic field, such as poorly shielded heavy-duty transformer.	Try turning off possible sources one by one. Move instrument from field source.
100-millivolt and all other ranges out of calibration, all same direction.	R144, R139, or R137 out of tolerance.	Check resistors; replace if faulty.
Only 0.01 and 0.03-microvolt or millivolt ranges out of calibration.	R149 or R150 out of tolerance.	Check resistors; replace if faulty.
All microvolt ranges out of calibration. The millivolt ranges are good.	R137, ratio B to A out of tolerance.	Check resistor; replace if faulty.
One range out of calibration.	Corresponding resistor in Table 11 out of tolerance.	Check resistor; replace if faulty.

TABLE 12 (Sheet 2). Amplifier Troubleshooting Table.

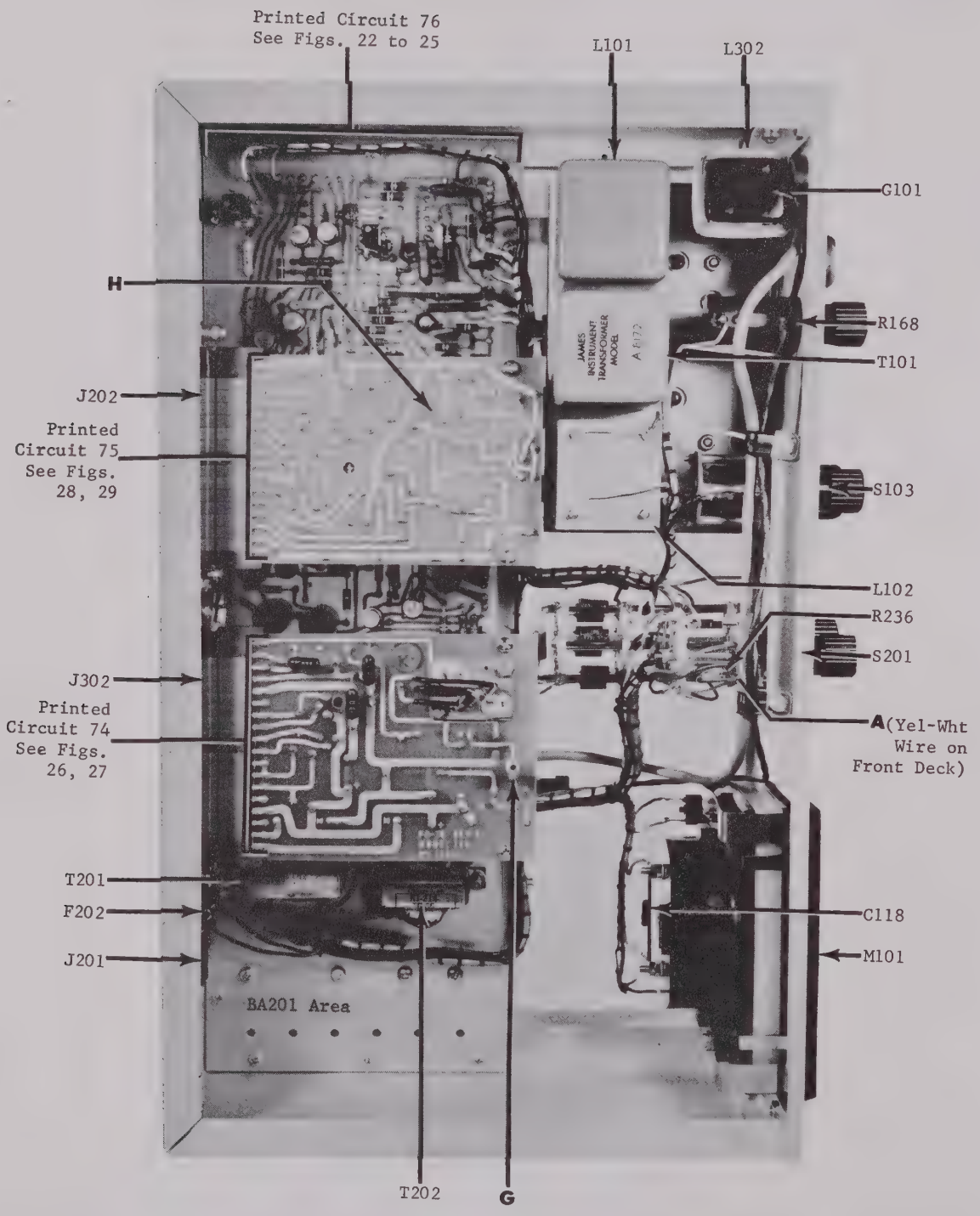


FIGURE 20. Top View of Model 148 Chassis. Location of components, printed circuits and some test points is shown above. Refer to Parts List for circuit designations.

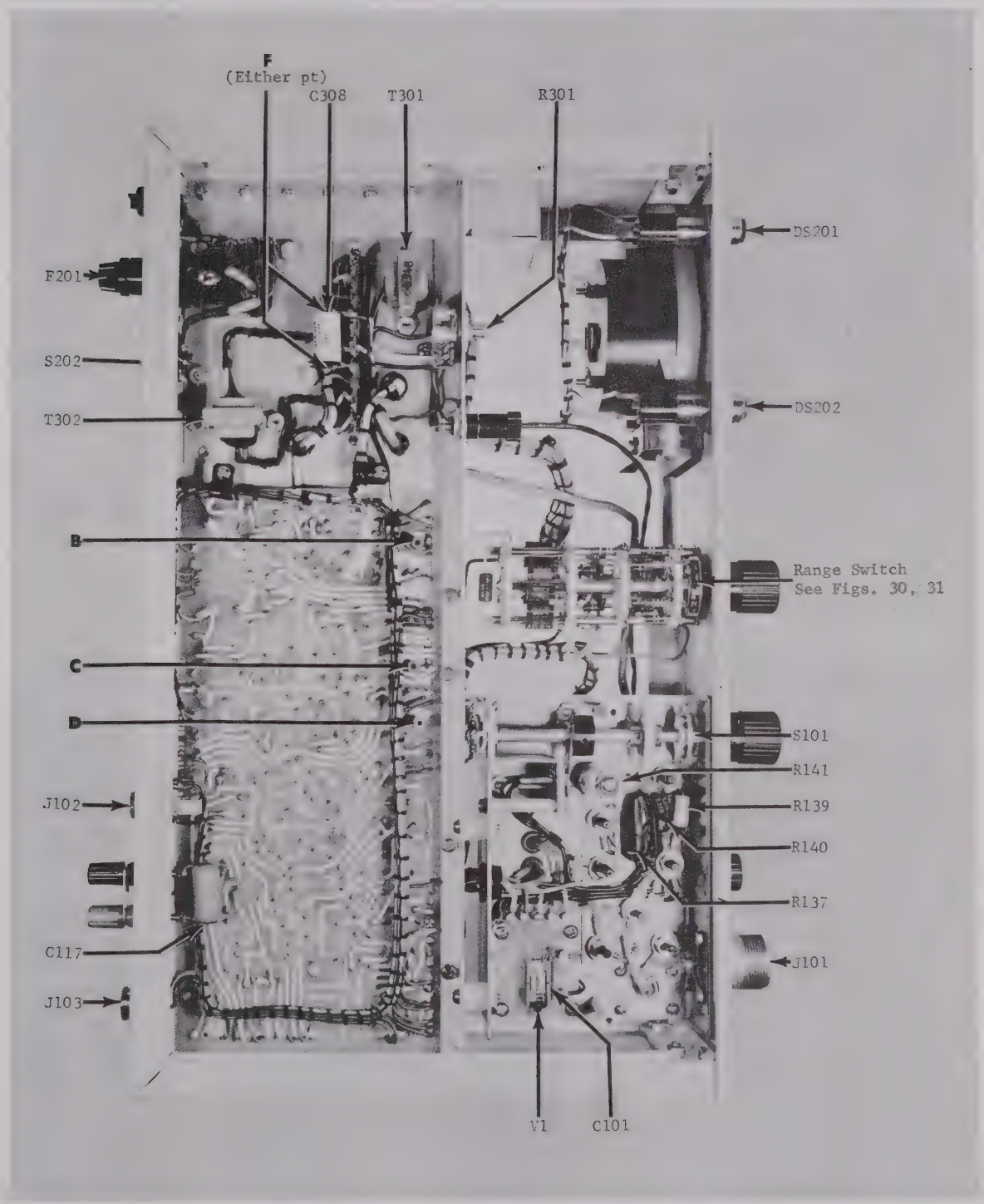


FIGURE 21. Bottom View of Model 148 Chassis. Locations of components and some test points is shown above. The input compartment is shown without its shield. Refer to Parts List for circuit designations.
* Connect to point F at either place, not to both points simultaneously.

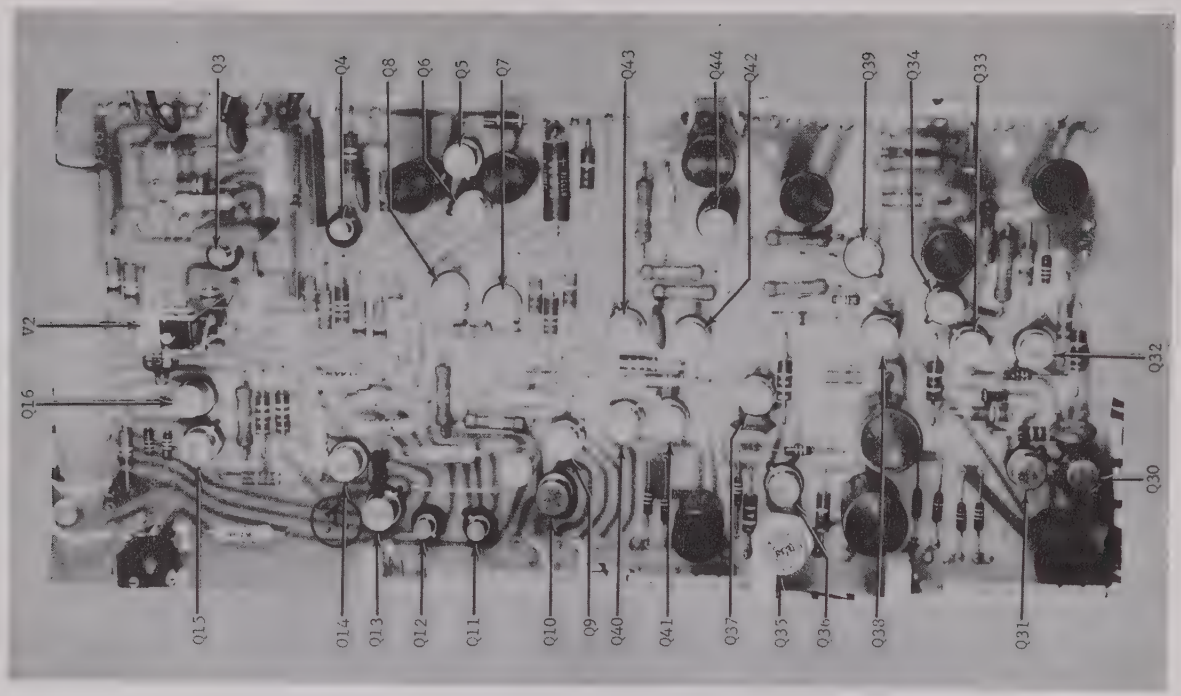


FIGURE 22. Transistor Locations on Printed Circuit 76.

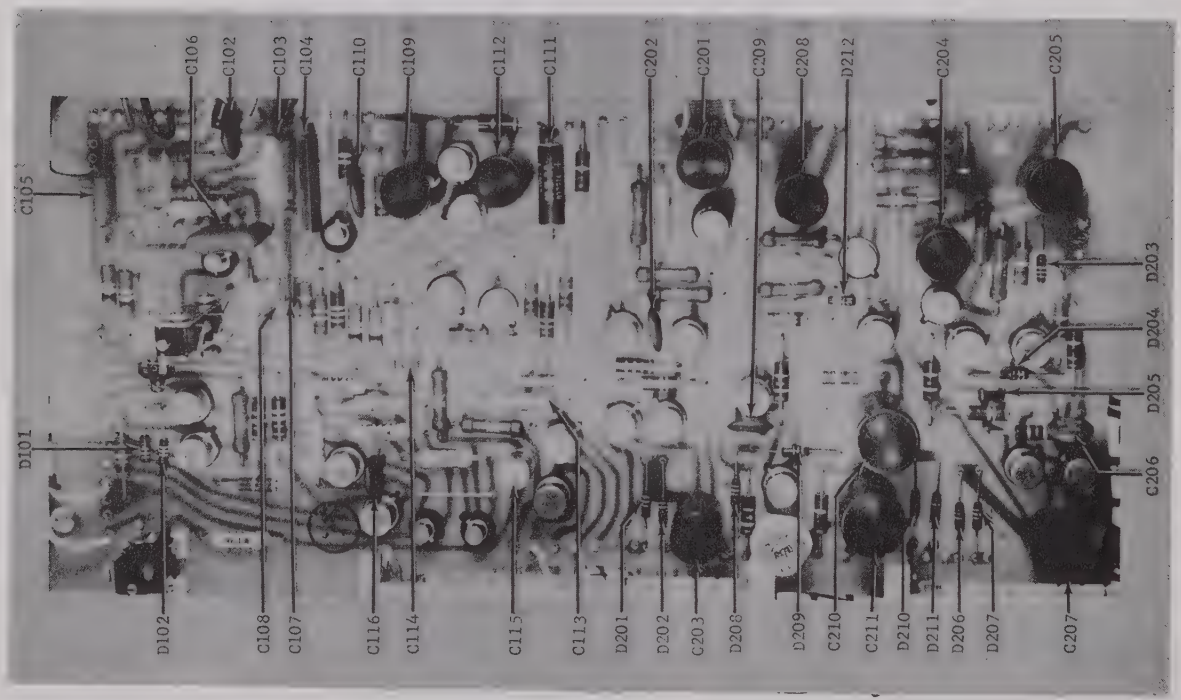


FIGURE 23. Capacitor and Diode Locations on Printed Circuit 76.

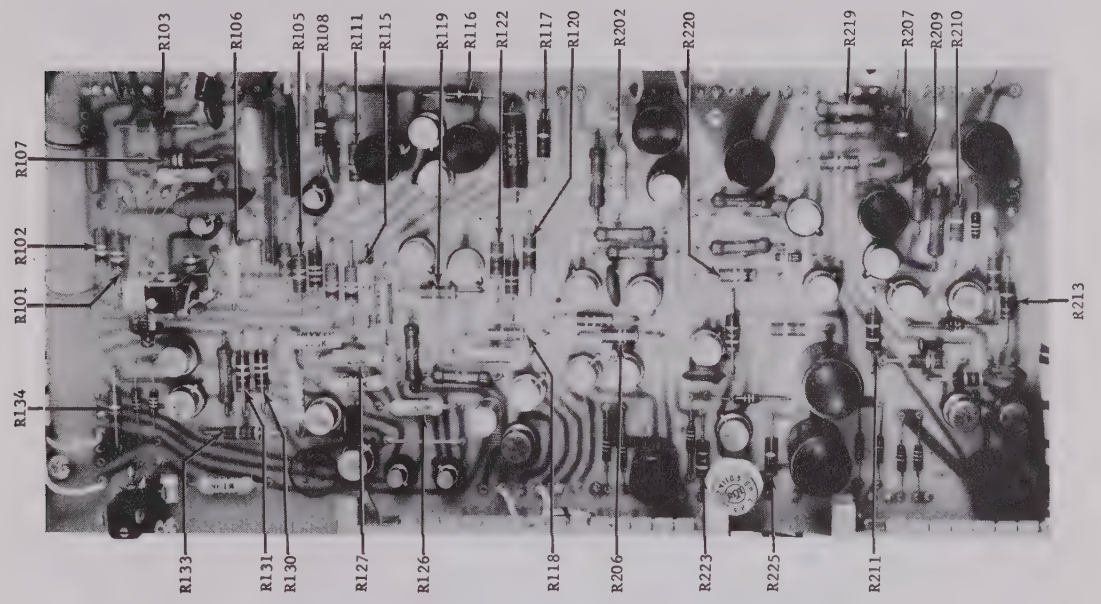


FIGURE 24. Resistor Locations on Printed Circuit 76. Figure 25 contains callouts for the other resistors.

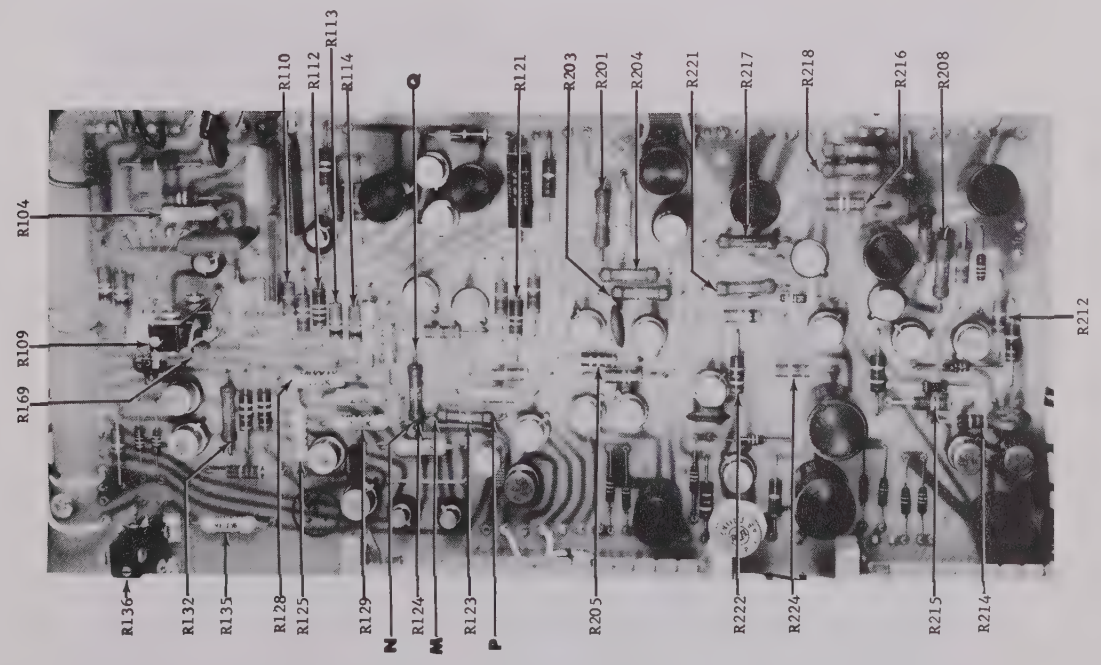


FIGURE 25. Resistor and Test Point Locations on Printed Circuit 76. Figure 24 contains callouts for the other resistors.

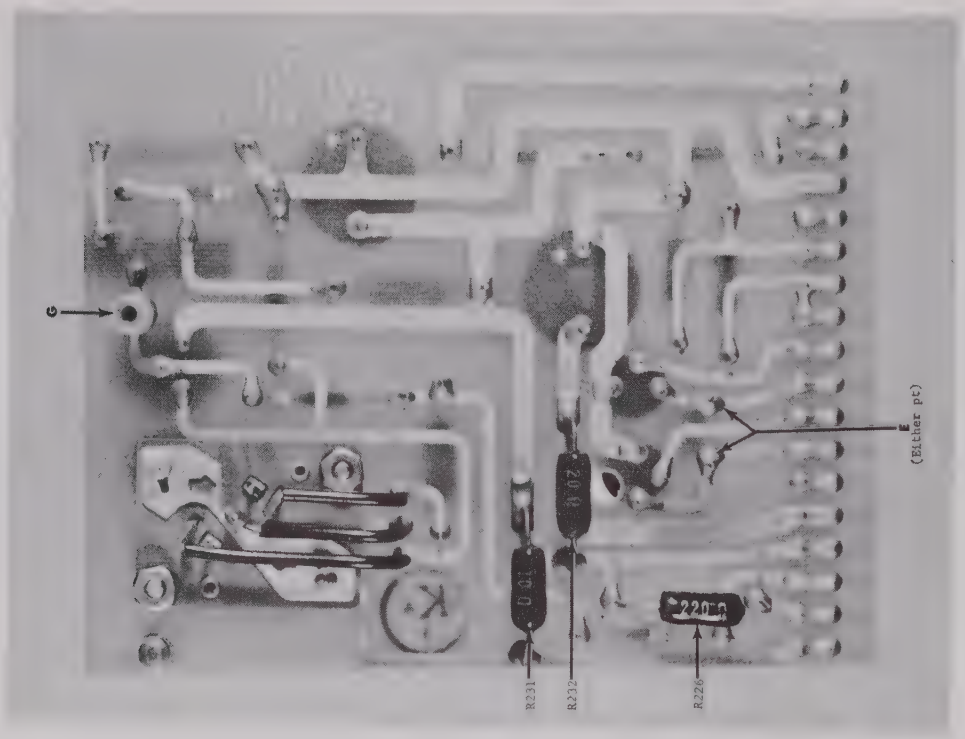


FIGURE 26. Resistor and Test Point Locations on Printed Circuit 74, Bottom Face.
* Connect to point E at either place, not to both points simultaneously.

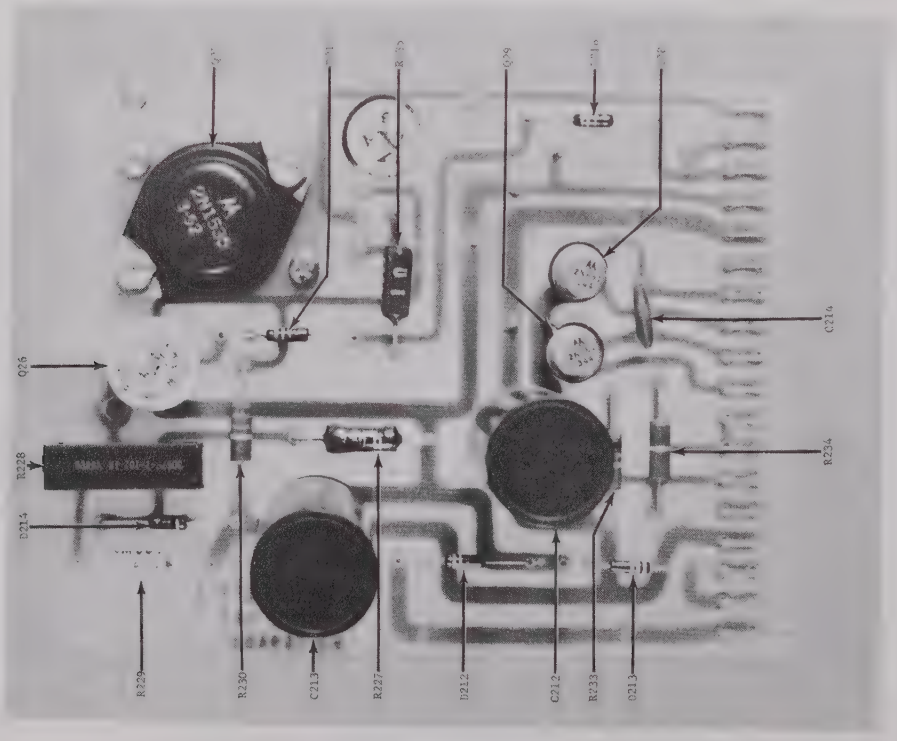


FIGURE 27. Component Locations on Printed Circuit 74, Top Face.

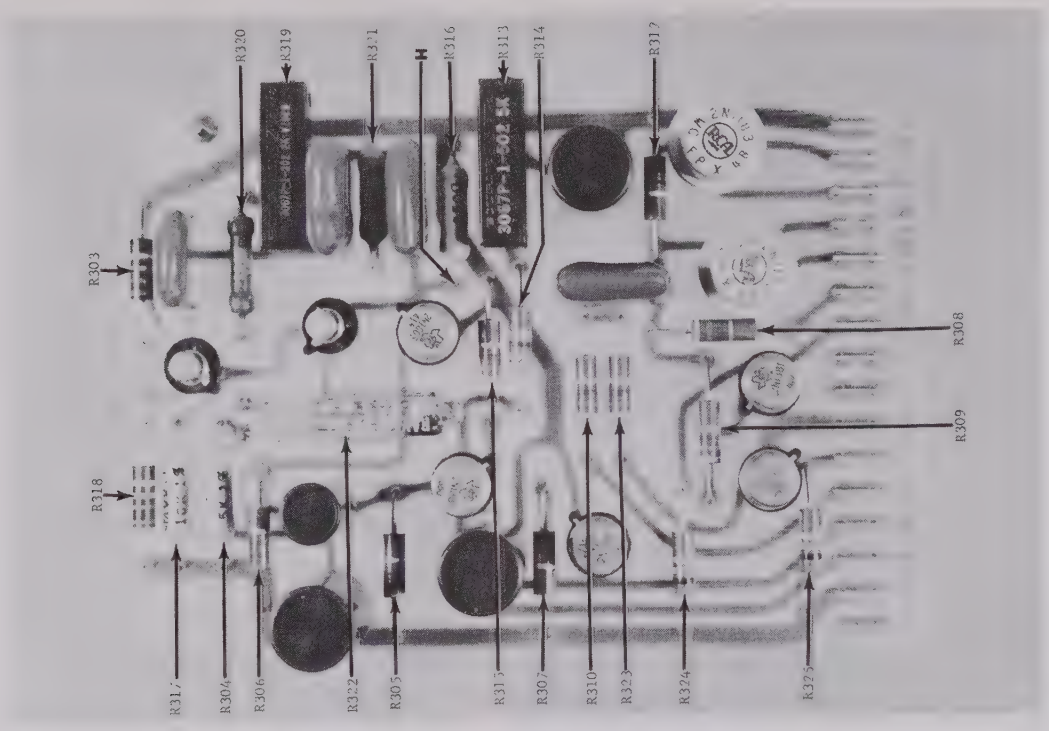


FIGURE 28. Resistor and Test Point Locations on Printed Circuit 75. An alternate location for point H is shown in Figure 20.

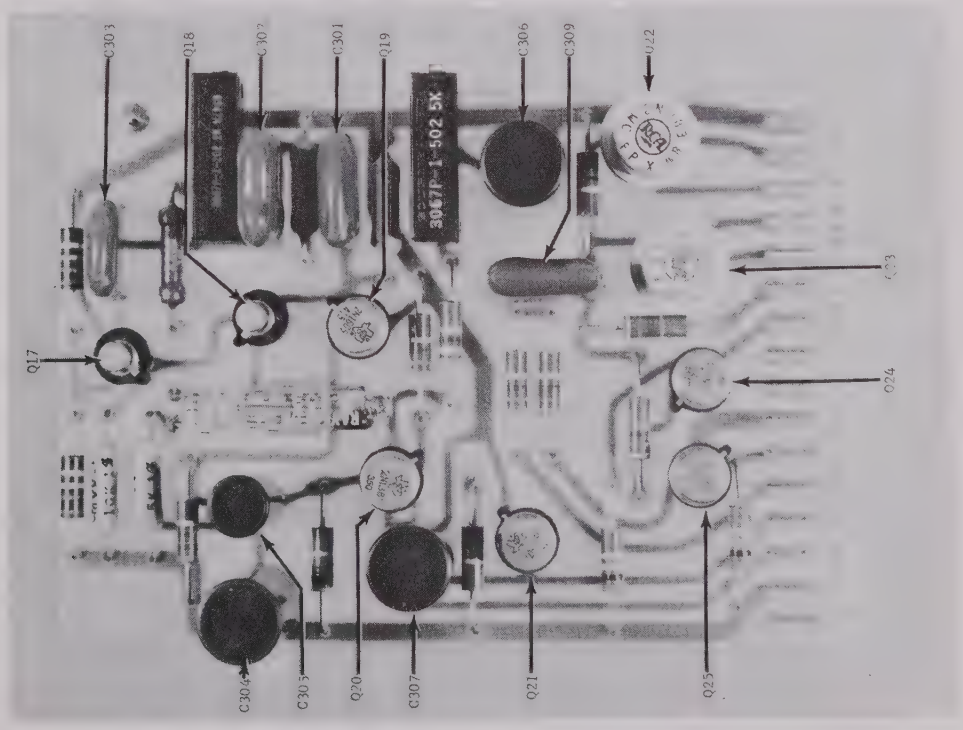


FIGURE 29. Capacitor and Transistor Locations on Printed Circuit 75.

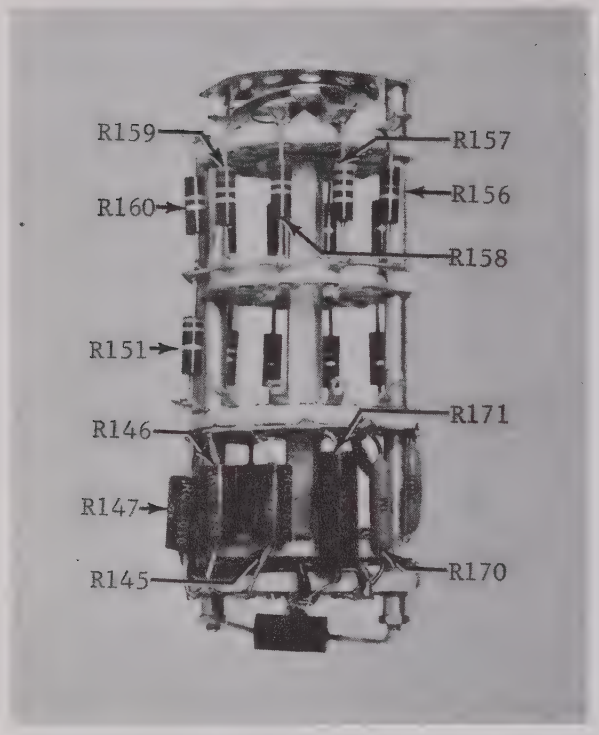


FIGURE 30. Resistor Locations on RANGE Switch (S102). Figure 31 shows resistors on opposite side.

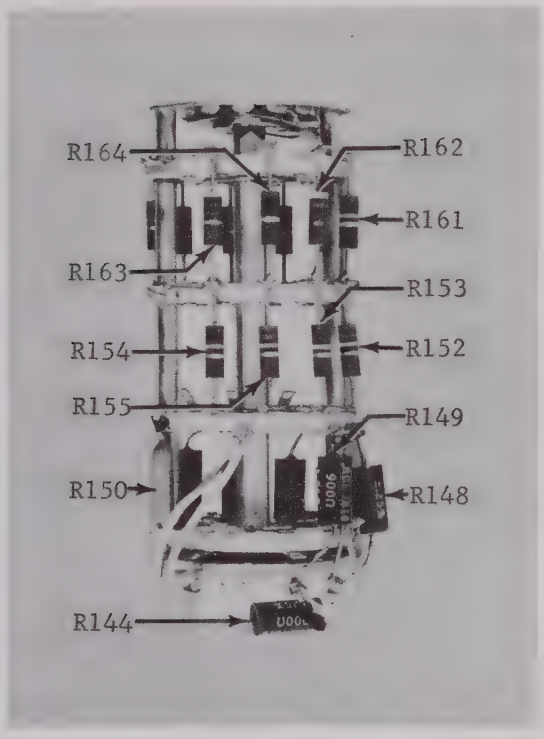


FIGURE 31. Resistor Locations on RANGE Switch (S102). Figure 30 shows resistors on opposite side.

SECTION 5. REPLACEABLE PARTS

5-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Model 148 and its accessories. The List gives the circuit designation, the part description, a suggested manufacturer and the Keithley Part Number. The last column indicates the figure picturing the part. The name and address of the manufacturers listed in the "Mfg. Code" column are contained in Table 14.

5-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial number, the Keithley Part Number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered from Keithley Instruments, Inc. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. Order parts through your nearest Keithley distributor or the Sales Service Department, Keithley Instruments, Inc.

amp	ampere	Mil. No.	Military Type Number
		My	Mylar
CbVar	Carbon Variable		
CerD	Ceramic, Disc	Ω	ohm
Comp	Composition		
		PMP	Metalized paper, phenolic case
DCb	Deposited Carbon	Poly	Polystyrene
		p	pico (10^{-12})
EAl	Electrolytic, Aluminum		
EMC	Electrolytic, metal cased	Ref.	Reference
ETB	Electrolytic, tubular		
ETT	Electrolytic, tantulum	μ	micro (10^{-6})
f	farad	v	volt
Fig.	Figure	Var	Variable
hy	henry	w	watt
		WW	Wirewound
k	kilo (10^{3})	WWenc	Wirewound encapsulated
		WWVar	Wirewound Variable
M or meg	mega (10^{6}) or megohms		
m	milli (10^{-3})		
Mfg.	Manufacturer		
MtF	Metal Film		

TABLE 13. Abbreviations and Symbols.

MODEL 148 REPLACEABLE PARTS LIST

(Refer to Schematic Diagram 17351F for circuit designations)

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
C101	.0143 µf	100 v	Poly	84171	C45-.0143M	21
C102	.01 µf	600 v	CerD	72982	C22-.01M	23
C103 (60 cps)	.184 µf	100 v	My	12673	C105-.184M	23
C103 (50 cps)	.109 µf	100 v	My	12673	C105-.109M	23
C104 (60 cps)	.0135 µf	100 v	Poly	84171	C45-.0135M	23
C104 (50 cps)	.0155 µf	100 v	Poly	84171	C45-.0155M	23
C105	.1 µf	50 v	My	84411	C41-.1M	23
C106	.22 µf	50 v	My	84411	C41-.22M	23
C107	.012 µf	100 v	Poly	84171	C45-.012M	23
C108	4.7 µf	10 v	ETB	05397	C71-4.7M	23
C109	100 µf	15 v	EA1	56289	C93-100M	23
C110	.01 µf	600 v	CerD	72982	C22-.01M	23
C111	25 µf	16 v	ETB	56289	C104-25M	23
C112	100 µf	15 v	EA1	56289	C93-100M	23
C113	10 µf	20 v	ETT	05397	C80-10M	23
C114	10 µf	20 v	ETT	05397	C80-10M	23
C115	25 µf	10 v	ETT (non-polar)	05079	C106-25M	23
C116	.01 µf	600 v	CerD	72982	C22-.01M	23
C117	.05 µf	600 v	My	56289	C62-.05M	21
C118	200 µf	3 v	EA1	14655	C48-200M	
C201	100 µf	15 v	EA1	56289	C93-100M	23
C202	.01 µf	600 v	CerD	72982	C22-.01M	23
C203	100 µf	15 v	EA1	56289	C93-100M	23
C204	100 µf	15 v	EA1	56289	C93-100M	23
C205	100 µf	15 v	EA1	56289	C93-100M	23
C206	.01 µf	600 v	CerD	72982	C22-.01M	23
C207	100 µf	25 v	PMP	56289	C94-100M	23
C208	100 µf	15 v	PMP	56289	C93-100M	23
C209	.01 µf	600 v	CerD	72982	C22-.01M	23
C210	100 µf	25 v	PMP	56289	C94-100M	23
C211	100 µf	25 v	PMP	56289	C94-100M	23

Refer to page 52 for higher designations.

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
D101	Silicon	1N645	83125	RF-14	23
D102	Silicon	1N645	83125	RF-14	23
D103	Zener	1N709	12954	DZ-21	
D104	Zener	1N709	12954	DZ-21	

DIODES (Cont'd)

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
D201	Silicon	1N645	83125	RF-14	23
D202	Silicon	1N645	83125	RF-14	23
D203	Silicon	1N645	83125	RF-14	23
D204	Silicon	1N645	83125	RF-14	23
D205	Zener	Special	80164	DZ-13	23
D206	Silicon	1N645	83125	RF-14	23
D207	Silicon	1N645	83125	RF-14	23
D208	Silicon	1N645	83125	RF-14	23
D209	Silicon	1N645	83125	RF-14	23
D210	Silicon	1N645	83125	RF-14	23
D211	Silicon	1N645	83125	RF-14	23
D212	Silicon	1N645	83125	RF-14	23

Refer to page 52 for higher designations.

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
G101	Chopper	80164	17689A	20
J101	Receptacle, INPUT, Special	80164	17638A	2
---	Plug, Special, Mate of J101	80164	CS-132	
J102	Jack, Telephone, DEMODULATOR TEST (Mfg. No. 275)	83330	CS-65	3
J103	Receptacle, Microphone, OUTPUT (Mfg. No. 80PC2F)	02660	CS-32	3
---	Plug, Microphone, Mate of J103 (Mfg. No. 80MC2M)	02660	CS-33	--
J202	Connector (Mfg. No. 00-5002-18-A-2-1-B)	91662	CS-125	20
J301	Connector (Mfg. No. 02-016-013-5200)	91662	CS-124	20
J302	Receptacle			
---	. Locking Ring (Mfg. No. 126-1430)	02660	CS-165	
---	. Receptacle (Mfg. No. 126-1429)	02660	CS-163	
---	. Body (Mfg. No. 126-1425)	02660	CS-161	
---	Binding Post, LO (Mfg. No. DF21BC)	58474	BP-11B	3
---	Binding Post, GND (Mfg. No. DF21GC)	58474	BP-11G	3
---	Shorting Link (Mfg. No. 938-L)	24655	BP-6	--

MISCELLANEOUS PARTS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
L101	Choke, 200 hy	80164	CH-1	20
L102	Choke, 120/80 hy	80164	CH-5	20
M101	Meter	80164	ME-14	20
S101	Rotary Switch less components, FUNCTION	80164 **		2
---	Knob Assembly, Function Switch	80164	16323A	
S102	Rotary Switch less components, RANGE	80164	SW-157	2
---	Switch Assembly with components, Range	80164	17632B	
---	Knob Assembly, Range Switch	80164	16323A	
S103	Rotary Switch less components, ZERO SUPPRESS COARSE	80164	SW-58	2
---	Switch Assembly with components, Coarse	80164	17626B	
---	Knob Assembly, Coarse Switch	80164	14838A	
S201	Rotary Switch less components, POWER SUPPLY	80164	SW-158	2
---	Knob Assembly, Power Supply Switch	80164	14838A	
S202	Slide Switch, 117 234	80164	SW-151	
---	Knob Assembly, Fine Potentiometer	80164	15110A	2
T101	Transformer	80164	17623B	20
T202	Transformer	80164	TR-65	20

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
R101	100 kΩ	10%, 1/2 w	Comp	01121	R1-100K	24
R102	100 kΩ	10%, 1/2 w	Comp	01121	R1-100K	24
R103	*4.7 MΩ	10%, 1/2 w	Comp	01121	R1-4.7M	24
R104	250 kΩ	1%, 1/2 w	DCb	79727	R12-250K	25
R105	22 kΩ	10%, 1/2 w	Comp	01121	R1-22K	24
R106	250 kΩ	1%, 1/2 w	DCb	79727	R12-250K	24
R107	100 kΩ	10%, 1/2 w	Comp	01121	R1-100K	24
R108	22 kΩ	10%, 1/2 w	Comp	01121	R1-22K	24
R109	100 kΩ	10%, .2 w	CbVar	80294	RP40-100K	25
R110	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	25
R111	22 kΩ	10%, 1/2 w	Comp	01121	R1-22K	24
R112	27 kΩ	10%, 1/2 w	Comp	01121	R1-27K	25
R113	10 kΩ	10%, 1/2 w	Comp	01121	R1-10K	25
R114	10 kΩ	10%, 1/2 w	Comp	01121	R1-10K	25
R115	470 Ω	10%, 1/2 w	Comp	01121	R1-470	24

* Nominal value, factory set.
** S101 consists of two switches, SW-160 and SW-161, and a coupling, CU-5.

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
R116	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	24
R117	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	24
R118	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	24
R119	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	24
R120	8.2 kΩ	10%, 1/2 w	Comp	01121	R1-8.2K	24
R121	150 Ω	10%, 1/2 w	Comp	01121	R1-150	25
R122	8.2 kΩ	10%, 1/2 w	Comp	01121	R1-8.2K	24
R123	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	25
R124	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	25
R125	50 kΩ	1%, 1/2 w	DCb	79727	R12-50K	25
R126	50 kΩ	1%, 1/2 w	DCb	79727	R12-50K	24
R127	250 Ω	1%, 1/2 w	DCb	79727	R12-250	24
R128	120 kΩ	1%, 1/2 w	DCb	79727	R12-120K	25
R129	120 kΩ	1%, 1/2 w	DCb	79727	R12-120K	25
R130	12 kΩ	10%, 1/2 w	Comp	01121	R1-12K	24
R131	12 kΩ	10%, 1/2 w	Comp	01121	R1-12K	24
R132	25 kΩ	1%, 1/2 w	DCb	79727	R12-25K	25
R133	470 Ω	10%, 1/2 w	Comp	01121	R1-470	24
R134	100 Ω	10%, 1/2 w	Comp	01121	R1-100	24
R135	8.6 kΩ	1%, 1/2 w	DCb	79727	R12-8.6K	25
R136	2 kΩ	10%, 1/2 w	WWVar	80294	RP35-2K	25
R137A & B	1 kΩ & 1Ω	Special	WW	80164	17627A	21
R138	Not Used					
R139	111 Ω	1/4%, 1/3 w	WWenc	80164	17635A	21
R140	1.11 kΩ	1/4%, 1/3 w	WWenc	80164	17636A	21
R141	10 kΩ	5%, 1/2 w	Comp	80164	17637A	21
R142	Not Used					
R143	Not Used					
R144	900 Ω	1/4%, 1/3 w	WWenc	01686	R105-900	31
R145	99 kΩ	1/4%, 1/3 w	WWenc	01686	R105-99K	30
R146	32.3 kΩ	1/4%, 1/3 w	WWenc	01686	R105-32.3K	30
R147	9 kΩ	1/4%, 1/3 w	WWenc	01686	R105-9K	30
R148	2.33 kΩ	1/4%, 1/3 w	WWenc	01686	R105-2.33K	31
R149	900 Ω	1/4%, 1/3 w	WWenc	01686	R105-900	31
R150	100 Ω	1/4%, 1/3 w	WWenc	01686	R105-100	31
R151	3.3 MΩ	10%, 1/2 w	Comp	01121	R1-3.3M	30
R152	* 680 kΩ	10%, 1/2 w	Comp	01121	R1-680K	31
R153	* 330 kΩ	10%, 1/2 w	Comp	01121	R1-330K	31
R154	*100 kΩ	10%, 1/2 w	Comp	01121	R1-100K	31
R155	*47 kΩ	10%, 1/2 w	Comp	01121	R1-47K	31
R156	*1 MΩ	10%, 1/2 w	Comp	01121	R1-1M	30
R157	330 kΩ	10%, 1/2 w	Comp	01121	R1-330K	30

* Nominal value, factory set.

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
R158	150 kΩ	10%, 1/2 w	Comp	01121	R1-150K	30
R159	68 kΩ	10%, 1/2 w	Comp	01121	R1-68K	30
R160	22 kΩ	10%, 1/2 w	Comp	01121	R1-22K	30
R161	6.8 kΩ	10%, 1/2 w	Comp	01121	R1-6.8K	31
R162	3.3 kΩ	10%, 1/2 w	Comp	01121	R1-3.3K	31
R163	1 kΩ	10%, 1/2 w	Comp	01121	R1-1K	31
R164	470 Ω	10%, 1/2 w	Comp	01121	R1-470	31
R165	4.7 MΩ	1%, 1/2 w	DCb	79727	R12-4.7M	**
R166	1 MΩ	1%, 1/2 w	DCb	79727	R12-1M	**
R167	100 kΩ	1%, 1/2 w	DCb	79727	R12-100K	**
R168	10 kΩ	3%, 1.5 w	WWVar	73138	RP41-10K	20
R169	*33 kΩ	10%, 1/2 w	Comp	01121	R1-33K	25
R170	1 MΩ	1/2%, 1/2 w	MtF	75042	R61-1M	30
R171	332 kΩ	1/4%, 1/3 w	WWenc	01686	R105-332K	30
R172	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	**
R201	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	25
R202	9 kΩ	1%, 1/2 w	DCb	79727	R12-9K	24
R203	22 kΩ	1%, 1/2 w	DCb	79727	R12-22K	25
R204	1 kΩ	1%, 1/2 w	DCb	79727	R12-1K	25
R205	12 kΩ	10%, 1/2 w	Comp	01121	R1-12K	25
R206	15 kΩ	10%, 1/2 w	Comp	01121	R1-15K	24
R207	1 kΩ	10%, 1/2 w	Comp	01121	R1-1K	24
R208	7 kΩ	1%, 1/2 w	DCb	79727	R12-7K	25
R209	7 kΩ	1%, 1/2 w	DCb	79727	R12-7K	24
R210	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	24
R211	2.7 kΩ	10%, 1/2 w	Comp	01121	R1-2.7K	24
R212	6.8 kΩ	10%, 1/2 w	Comp	01121	R1-6.8K	25
R213	22 Ω	10%, 1/2 w	Comp	01121	R1-22	24
R214	2.7 kΩ	10%, 1/2 w	Comp	01121	R1-2.7K	25
R215	15 kΩ	10%, 1/2 w	Comp	01121	R1-15K	25
R216	22 kΩ	10%, 1/2 w	Comp	01121	R1-22K	25
R217	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	25
R218	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	25
R219	4.7 kΩ	1%, 1/2 w	DCb	79727	R12-4.7K	24
R220	10 kΩ	10%, 1/2 w	Comp	01121	R1-10K	24
R221	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	25
R222	2.7 kΩ	10%, 1/2 w	Comp	01121	R1-2.7K	25
R223	2.7 Ω	10%, 1/2 w	Comp	01121	R1-2.7	24
R224	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	25
R225	1 kΩ	10%, 1/2 w	Comp	01121	R1-1K	24

Refer to page 53 for higher designations.

* Nominal value, factory set.

** These resistors are located in S103, Figure 20.

TRANSISTORS

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Q1	Not Used			
Q2	Not Used			
Q3	A1294	73445	TG-29	22
Q4	A1294	73445	TG-29	22
Q5	2N1381	01295	TG-8	22
Q6	2N1381	01295	TG-8	22
Q7	2N1381	01295	TG-8	22
Q8	2N1381	01295	TG-8	22
Q9	2N1381	01295	TG-8	22
Q10	2N1381	01295	TG-8	22
Q11	**A1294	80164	17978A	22
Q12	**A1294	80164	17978A	22
Q13	2N1381	01295	TG-8	22
Q14	2N1381	01295	TG-8	22
Q15	2N1605	93332	TG-22	22
Q16	2N1381	01295	TG-8	22

Refer to page 55 for designations Q17 to Q25 and to page 53 for Q26 to Q29.

Q30	2N1381	01295	TG-8	22
Q31	2N1381	01295	TG-8	22
Q32	2N1381	01295	TG-8	22
Q33	2N1381	01295	TG-8	22
Q34	2N1381	01295	TG-8	22
Q35	2N1183	02735	TG-11	22
Q36	2N1381	01295	TG-8	22
Q37	2N1381	01295	TG-8	22
Q38	2N1381	01295	TG-8	22
Q39	2N1381	01295	TG-8	22
Q40	2N1605	93332	TG-22	22
Q41	2N1605	93332	TG-22	22
Q42	2N1605	93332	TG-22	22
Q43	2N1381	01295	TG-8	22
Q44	2N1381	01295	TG-8	22

VACUUM TUBES

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
V1	CK512AX	80164	EV-512AX	21
V2	CK512AX	80164	EV-512AX	22

** Q11 and Q12 are matched during manufacture; replace only as pair.

NOTE

Refer to Schematic Diagram 17352D for circuit designations.

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 46 for lower designations.						
C212	500 μf	25 v	EAl	56289	C94-500M	27
C213	500 μf	25 v	EAl	56289	C94-500M	27
C214	.01 μf	600 v	CerD	72982	C22-.01M	27
Refer to page 54 for higher designations.						

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 47 for lower designations.					
D212	Silicon	1N645	83125	RF-14	27
D213	Silicon	1N645	83125	RF-14	27
D214	Zener	1N713	12954	DZ-14	27
D215	Silicon	1N645	83125	RF-14	27
D216	Silicon	1N645	83125	RF-14	27

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
BA201	Battery Pack, 6-volt 4-amp-hr nickel-cadmium	80164	Model 148920	
DS201	Bulb, AC CONNECTED, bayonet base (Mfg. No. 49)	08804	PL-23	2
---	Light Socket, Red (Mfg. No. 81410-231)	72619	PL-5R	
DS202	Bulb, BATTERY CHARGING, bayonet base (Mfg. No. 49)	08804	PL-23	2
---	Light Socket, Amber (Mfg. No. 81410-233)	72619	PL-5A	
F201 (117 v)	Fuse, 1/8 amp, 3 AG, type MDL	71400	FU-20	21
F201 (234 v)	Fuse, 1/16 amp, 3 AG, type MDL	71400	FU-21	3
---	Fuse Holder	75915	FH-3	
F202	Fuse, 1 amp, 8 AG	75915	FU-1	20
J201	Terminal Block (Mfg. No. 3008)	83330	TE-47	20
J202	Connector (Mfg. No. 02-018-013-5200)	91662	CS-127	20

MISCELLANEOUS PARTS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
---	Line Cord	80164	CO-5	3
---	Line Cord Clamp	80164	CC-4	
S201	Rotary Switch (See pg. 48)	80164	SW-158	
S202	Slide Switch, Line Voltage	80164	SW-151	3
T201	Transformer	80164	TR-63	20

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 50 for lower designations.						
R226	*220 Ω	.1%, 2 w	WW	01686	R92-220	26
R227	330 Ω	.1%, 2 w	WW	01686	R92-330	27
R228	1 kΩ	10%, 1/2 w	WWVar	80294	RP39-1K	27
R229	1.8 kΩ	1%, 1/2 w	DCb	79727	R12-1.8K	27
R230	680 Ω	10%, 1/2 w	Comp	01121	R1-680	27
R231	10 Ω	.1%, 2 w	WW	01686	R92-10	26
R232	18 Ω	.1%, 2 w	WW	01686	R92-18	26
R233	100 Ω	10%, 1/2 w	Comp	01121	R1-100	27
R234	1.5 kΩ	10%, 1/2 w	Comp	01121	R1-1.5K	27
R235	1 Ω	.1%, 2 w	WW	01686	R92-1	20
R236	75 kΩ	1%, 1/2 w	DCb	79727	R12-75K	27
Refer to page 54 for higher designations.						

TRANSISTORS

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 55 for lower designations.				
Q26	2N1183	02735	TG-11	27
Q27	2N1535	04713	TG-7	27
Q28	2N651	04713	TG-9	27
Q29	2N651	04713	TG-9	27
Refer to page 51 for higher designations.				

* Nominal value, factory set.

NOTE

Refer to Schematic Diagram 17353D for circuit designations.

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 52 for lower designations.						
C301	.22 μf	50 v	My	84411	C41-.22M	29
C302	.22 μf	50 v	My	84411	C41-.22M	29
C303	.1 μf	50 v	My	84411	C41-.1M	29
C304	100 μf	15 v	PMP	56289	C93-100M	29
C305	10 μf	15 v	PMP	56289	C93-10M	29
C306	100 μf	15 v	PMP	56289	C93-100M	29
C307	100 μf	15 v	PMP	56289	C93-100M	29
C308	1 μf	200 v	My	83125	C66-1M	21
C309	.22 μf	50 v	My	84411	C41-.22M	29

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
J301	Connector (Mfg. No. 02-016-013-5200)	91662	CS-126	20
J302	Connector			
---	. Nut (Mfg. No. 41-153)	02660	CS-160	
---	. Locking Ring (Mfg. No. 126-1428)	02660	CS-164	
---	. Plug (Mfg. No. 126-1427)	02660	CS-162	
L302	Degausing Coil	80164	CH-6	20
T301	Transformer	80164	TR-64	21
T302	Transformer	80164	TR-68	21

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 53 for lower designations.						
R301	2 Ω	10%, 5 w	WWVar	71450	RP34-2	21
R302	*0 Ω	10%, 1/2 w	Comp	01121	R1-0	--
R303	12 kΩ	10%, 1/2 w	Comp	01121	R1-12K	28
R304	5 kΩ	1%, 1/2 w	DCb	79727	R12-5K	28
R305	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	28
R306	8.2 kΩ	10%, 1/2 w	Comp	01121	R1-8.2K	28
R307	*15 kΩ	10%, 1/2 w	Comp	01121	R1-15K	28

* Nominal value, factory set.

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Fig. Ref.
R308	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	28
R309	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	28
R310	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	28
R311	Not Used					
R312	10 Ω	10%, 1/2 w	Comp	01121	R1-10	28
R313	5 kΩ	10%, 1/2 w	WWVar	80294	RP39-5K	28
R314	6.8 kΩ	10%, 1/2 w	Comp	01121	R1-6.8K	28
R315	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	28
R316	2.5 kΩ	1%, 1/2 w	DCb	79727	R12-2.5K	28
R317	10 kΩ	1%, 1/2 w	DCb	79727	R12-10K	28
R318	12 kΩ	10%, 1/2 w	Comp	01121	R1-12K	28
R319	2 kΩ	10%, 1/2 w	WWVar	80294	RP39-2K	28
R320	2.2 kΩ	1%, 1/2 w	DCb	79727	R12-2.2K	28
R321	4 kΩ	1%, 1/2 w	DCb	79727	R12-4K	28
R322	Special		Special	80164	PL-32	28
R323	4.7 kΩ	10%, 1/2 w	Comp	01121	R1-4.7K	28
R324	10 kΩ	10%, 1/2 w	Comp	01121	R1-10K	28
R325	10 kΩ	10%, 1/2 w	Comp	01121	R1-10K	28

TRANSISTORS

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Refer to page 51 for lower designations.				
Q17	A1294	73445	TG-29	29
Q18	A1294	73445	TG-29	29
Q19	2N1605	93332	TG-22	29
Q20	2N1381	01295	TG-8	29
Q21	2N1381	01295	TG-8	29
Q22	**2N1183	80164	18470A	29
Q23	**2N1183	80164	18470A	29
Q24	2N1381	01295	TG-8	29
Q25	2N1381	01295	TG-8	29

Refer to page 53 for higher designations.
** Q22 and Q23 are matched during manufacture; replace only as a pair.

MODEL 1481 REPLACEABLE PARTS LIST

Description	Mfg. Code	Keithley Part No.
Plug Assembly	80164	CS-132
Cable Assembly, 48 inches	80164	14731B
Copper Alligator Clips (2) (Mfg. No. 6005)	76545	AC-9

MODEL 1482 REPLACEABLE PARTS LIST

Description	Mfg. Code	Keithley Part No.
Plug Assembly	80164	CS-132
Cable Assembly, 10 feet	80164	14731B

MODELS 1483, 1484 REPLACEABLE PARTS LIST

Description	Quantity	Mfg. Code	Keithley Part No.	Used on Kit Model
Crimp Tool for Copper lugs	1	80164	TL-1	1483
#8 Nylon Screws	50	80164	---	1483, 1484
#8 Nylon Hex Nuts	50	80164	---	1483, 1484
Copper Bolt-on Lugs	100	80164	17340A	1483, 1484
Copper Spade Lugs	100	80164	17339A	1483, 1484
Copper Hook Lugs	100	80164	17336A	1483, 1484
Copper Splice Tubes	100	80164	17338A	1483, 1484
Low-Thermal Cadmium-Tin Solder	10 feet	80164	---	1483, 1484
Copper Alligator Clips (Mfg. No. 6005)	10	76545	AC-9	1483, 1484
Shielded Cable	10 feet	80164	SC-5	1483, 1484
Insulated #20 Copper Wire	100 feet	80164	WS-1	1483, 1484
Non-metalic Abrasive	3 pads	80164	17774A	1483, 1484

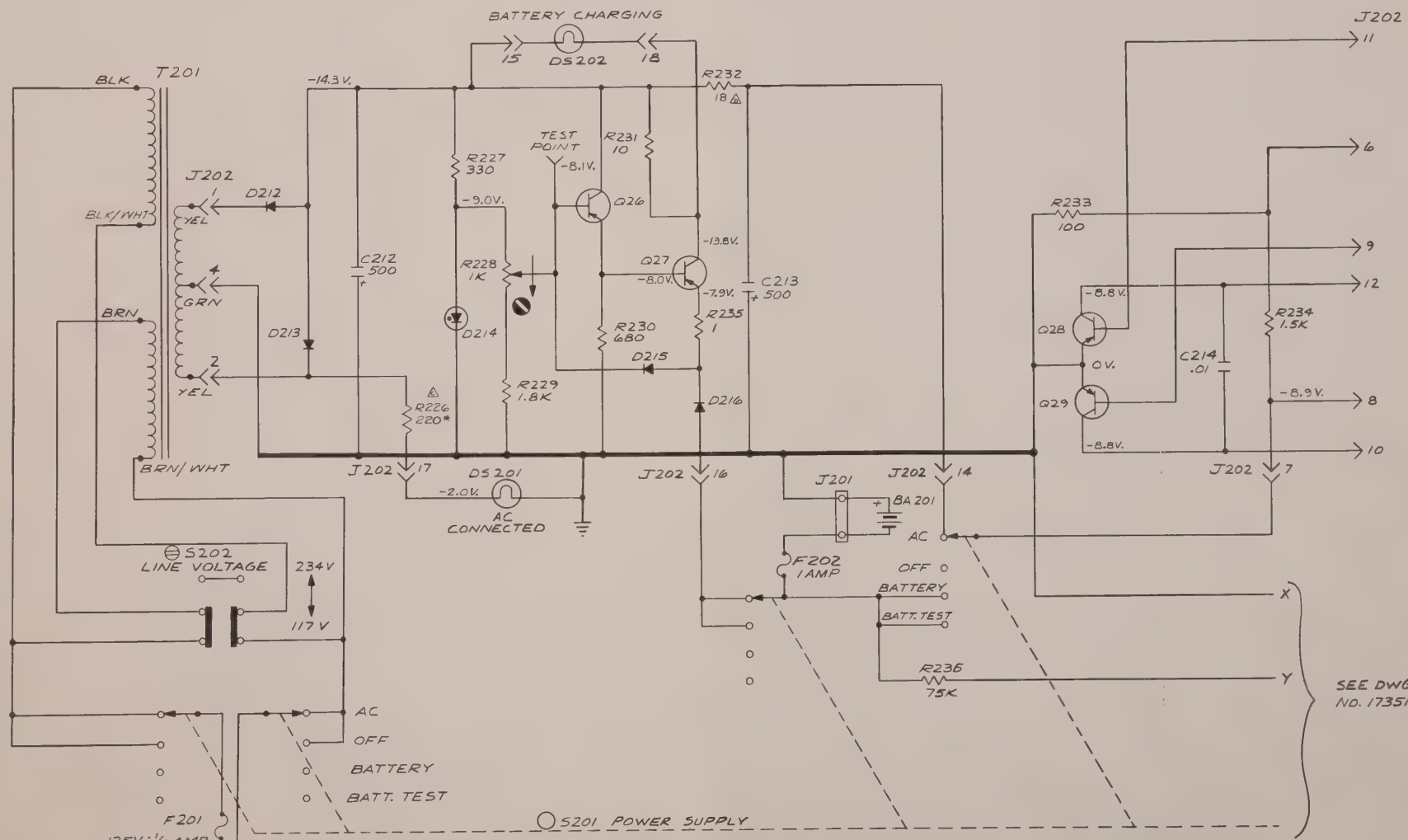
01121	Allen-Bradley Corp. Milwaukee, Wis.	05397	Kemet Co. Cleveland, Ohio
01295	Texas Instruments, Inc. Semi-Conductor Components Div. Dallas, Texas	08804	Lamp Metals and Components Dept. G. E. Co. Cleveland, Ohio
01686	RCL Electronics, Inc. Riverside, N. J.	09052	Gulton Industries, Inc. Alkaline Battery Division Metuchen, N. J.
02660	Amphenol-Borg Electronics Corp. Broadview, Chicago, Illinois	12673	Wesco Division of Atlee Corp. Greenfield, Mass.
02735	RCA Semiconductor & Materials Div. of Radio Corp. of America Somerville, N. J.	12954	Dickson Electronics Corp. Scottsdale, Ariz.
04713	Motorola, Inc. Semiconductor Products Division Phoenix, Arizona	15909	Daven Co. Livingston, N. J.

TABLE 14 (Sheet 1). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

0668R

24655	General Radio Co. West Concord, Mass.
44655	Ohmite Mfg. Co. Skokie, Ill.
56289	Sprague Electric Co. North Adams, Mass.
58474	Superior Electric Co., The Bristol, Conn.
71400	Bussmann Mfg. Div. of McGraw-Edison Co. St. Louis, Mo.
71450	CTS Corp. Elkhart, Ind.
72619	Dialight Corp. Brooklyn, N. Y.
72982	Erie Technological Products, Inc. Erie, Pa.
73138	Helipot Division of Beckman Instruments, Inc. Fullerton, Calif.
73445	Amperex Electronic Co. Division of North American Philips Co., Inc. Hicksville, N. Y.
75042	International Resistance Co. Philadelphia, Pa.
75915	Littelfuse, Inc. Des Plaines, Ill.
76545	Mueller Electric Co. Cleveland, Ohio
79727	Continental-Wirt Electronics Corp. Philadelphia, Pa.
80164	Keithley Instruments, Inc. Cleveland, Ohio
80294	Bourns Laboratories, Inc. Riverside, Calif.
83125	General Instrument Corp. Capacitor Division Darlington, S. C.
83330	Smith, Herman H., Inc. Brooklyn, N. Y.
84171	Arco Electronics, Inc. Great Neck, N. Y.
84411	Good-All Electric Mfg. Co. Ogallala, Nebr.
91662	Elco Corp. Willow Grove, Pa.
93332	Sylvania Electric Products, Inc. Semiconductor Div. Woburn, Mass.

TABLE 14 (Sheet 2). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)



NOTES:

1. ALL RESISTANCE AND CAPACITANCE SHALL BE DESIGNATED IN OHMS AND MICROFARADS RESPECTIVELY UNLESS OTHER WISE NOTED.
2. ⊘ INTERNAL SCREWDRIVER ADJUSTMENT.
3. K = 1000 OHMS
4. ↑ = CLOCKWISE ROTATION
5. ○ FRONT PANEL CONTROL.
6. ⊖ REAR PANEL ADJUSTMENT.
7. INDICATED VOLTAGES ARE D.C. VALUES MEASURED TO CIRCUIT GROUND WITH A 10 MEG. VTVM AT A LINE VOLTAGE OF 117V., ON THE 10 MICROVOLT RANGE WITH INPUT SHORTED.

REFERENCE DESIGNATIONS NOT USED

HIGHEST REFERENCE DESIGNATIONS			
R235	C214	D214	BA201
F202	DS202	Q29	T201
S202	J202		

REVISIONS			
LTR	ECO No	APPR	DATE
A	LABR	RTE	11-15-63
B	P0113	RTE	1-24-64
C	2732	RTE	11-5-65
D	3425	RTE	11-17-66

DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED: FRAC ± 1/64, DEC ± .005, ANG ± 1°. DO NOT SCALE.

DRN D.D.L DATE 2-6-64 | CKD S.S DATE 3-23-64 | ENG APPR R.T.E. DATE 3-23-64 | PILOT RELEASE S.S. DATE 3-25-64 | PROD RELEASE DATE

KEITHLEY INSTRUMENTS CLEVELAND OHIO

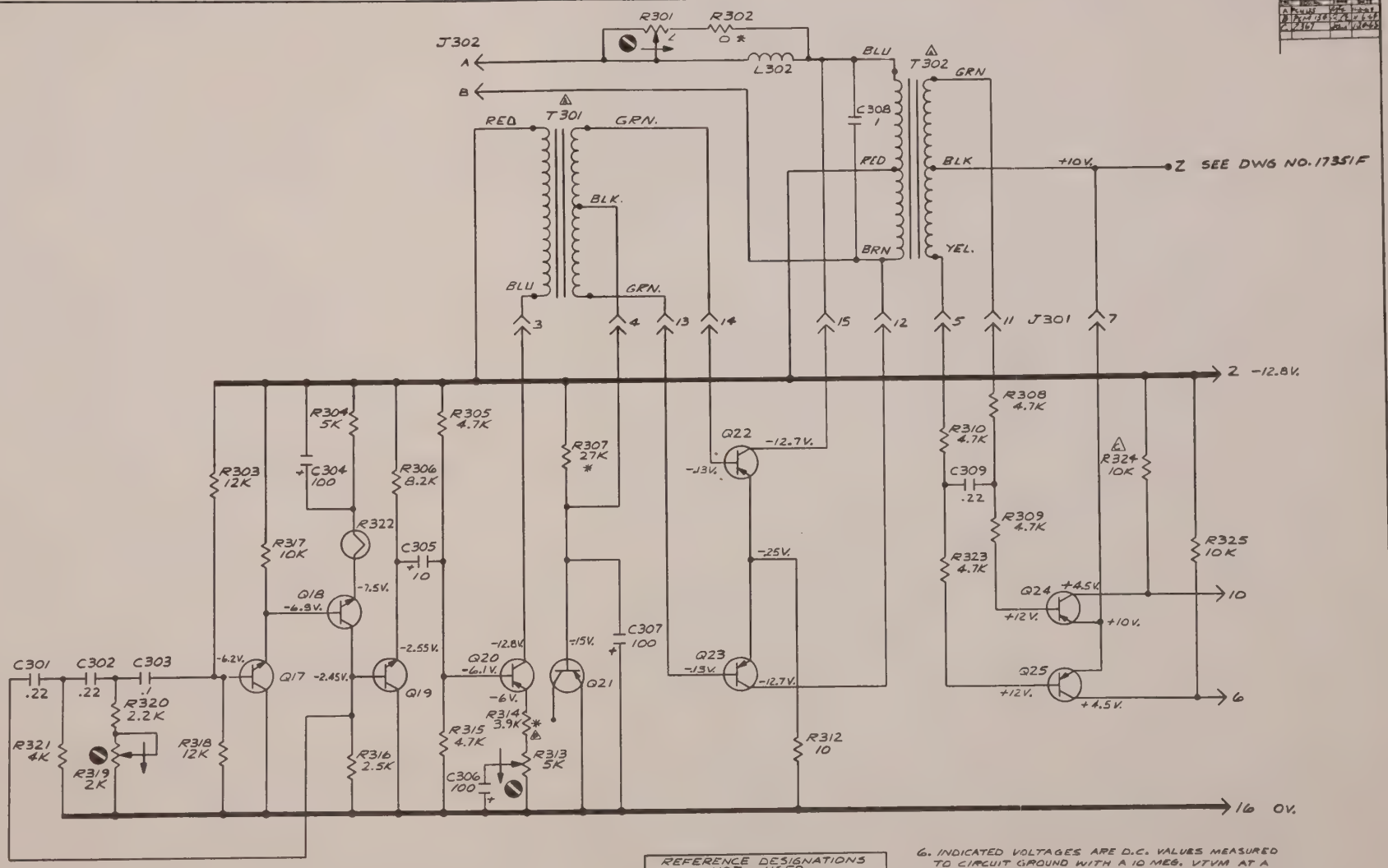
TITLE: SCHEMATIC, POWER SUPPLY

MATERIAL

PART NUMBER 17352D

MODEL	NEXT ASSEMBLY	DWG
147		1
148		

USED ON



NOTES:

1. ALL RESISTANCE AND CAPACITANCE SHALL BE DESIGNATED IN OHMS AND MICROFARADS RESPECTIVELY, UNLESS OTHERWISE NOTED.
2. * INDICATES NOMINAL VALUE ADJUSTED AT FACTORY.
3. ⊘ INTERNAL SCREWDRIVER ADJ.
4. K = 1000 OHMS
5. ↑ = C.W. ROTATION
6. INDICATED VOLTAGES ARE D.C. VALUES MEASURED TO CIRCUIT GROUND WITH A 10 MEG. VTVM AT A LINE VOLTAGE OF 117V., ON THE 10 MICROVOLT RANGE WITH INPUT SHORTED.

REFERENCE DESIGNATIONS NOT USED			
△ R311			

HIGHEST REFERENCE DESIGNATIONS			
R325	C309	Q25	L302
T302	T302		

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	PER ECO 1735-2	4-1-64	R.S.F.
B	PER ECO 1735-3	4-15-64	R.S.F.
C	PER ECO 1735-4	4-17-64	R.S.F.

DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED			
FRAC.	DEC.	ANG.	
± 1/64	± .005	± 1°	
DO NOT SCALE			

DRN D.D.L. DATE 2-7-64
CKD R.T.E. DATE 2-21-64
ENG APPR R.T.E. DATE 3-23-64
PILOT RELEASE S.S. DATE 3-29-64
PROD RELEASE M DATE 4-6-64

KEITHLEY INSTRUMENTS CLEVELAND, OHIO

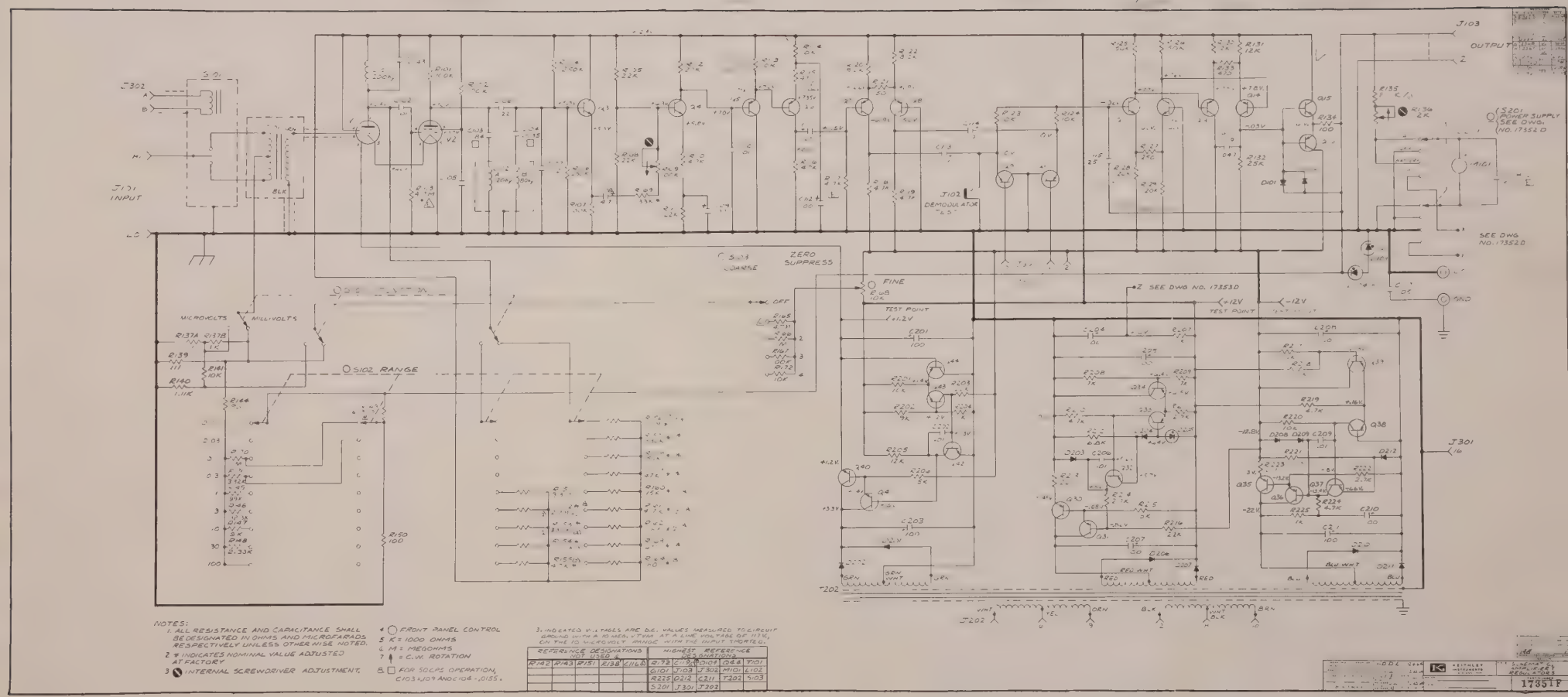
MATERIAL

FINISH

TITLE SCHEMATIC, OSCILLATOR

PART NUMBER 17353D

NEXT ASSEMBLY USED ON



NOTES:

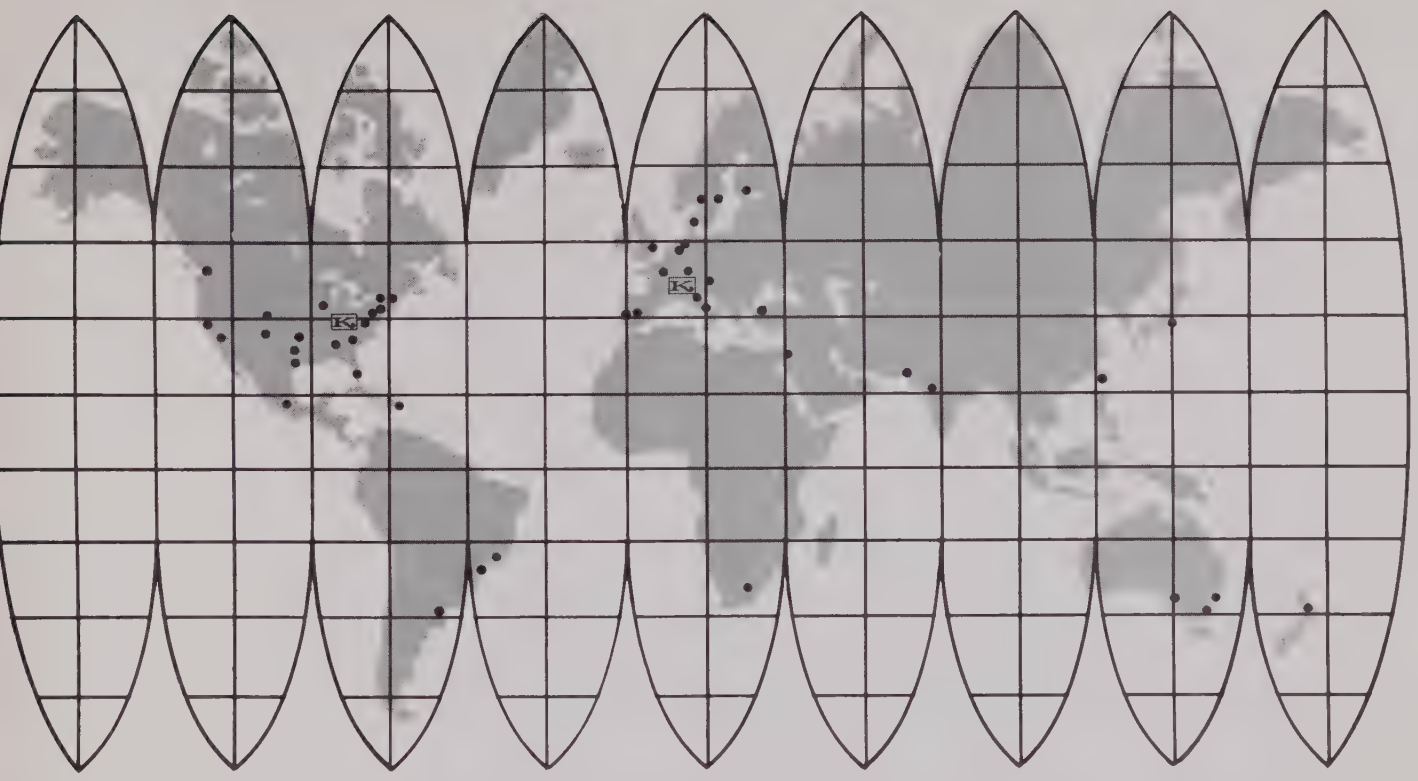
1. ALL RESISTANCE AND CAPACITANCE SHALL BE DESIGNATED IN OHMS, AND MICROFARADS, RESPECTIVELY UNLESS OTHERWISE NOTED.
2. ✻ INDICATES NOMINAL VALUE ADJUSTED AT FACTORY
3. ⊘ INTERNAL SCREWDRIVER ADJUSTMENT.
4. ◯ FRONT PANEL CONTROL
5. K = 1000 OHMS
6. M = MEGOHMS
7. ↑ = C.W. ROTATION
8. □ FOR 50 CPS OPERATION, C103 = .109 AND C104 = .0155.

3. INDICATED V.I. TAGES ARE D.C. VALUES MEASURED TO CIRCUIT GROUND WITH A 10 MEG, 7 PIN AT A LINE VOLTAGE OF 115V, ON THE 10 MICROVOLT RANGE WITH THE INPUT SHORTED.

REFERENCE DESIGNATIONS NOT USED					HIGHEST REFERENCE DESIGNATIONS				
R142	R143	R151	R138	C116	Q73	C109	D109	D64	T101
					Q101	J103	J302	M101	L102
					4225	D212	C211	T201	S103
					S201	J301	J202		

KEITHLEY INSTRUMENTS

17351F



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I-20122 Milano
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Roma
Telephone: 772-941

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Instrumentation, Pty. Ltd.
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pa Vallingby
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Telephone: 87-03-30

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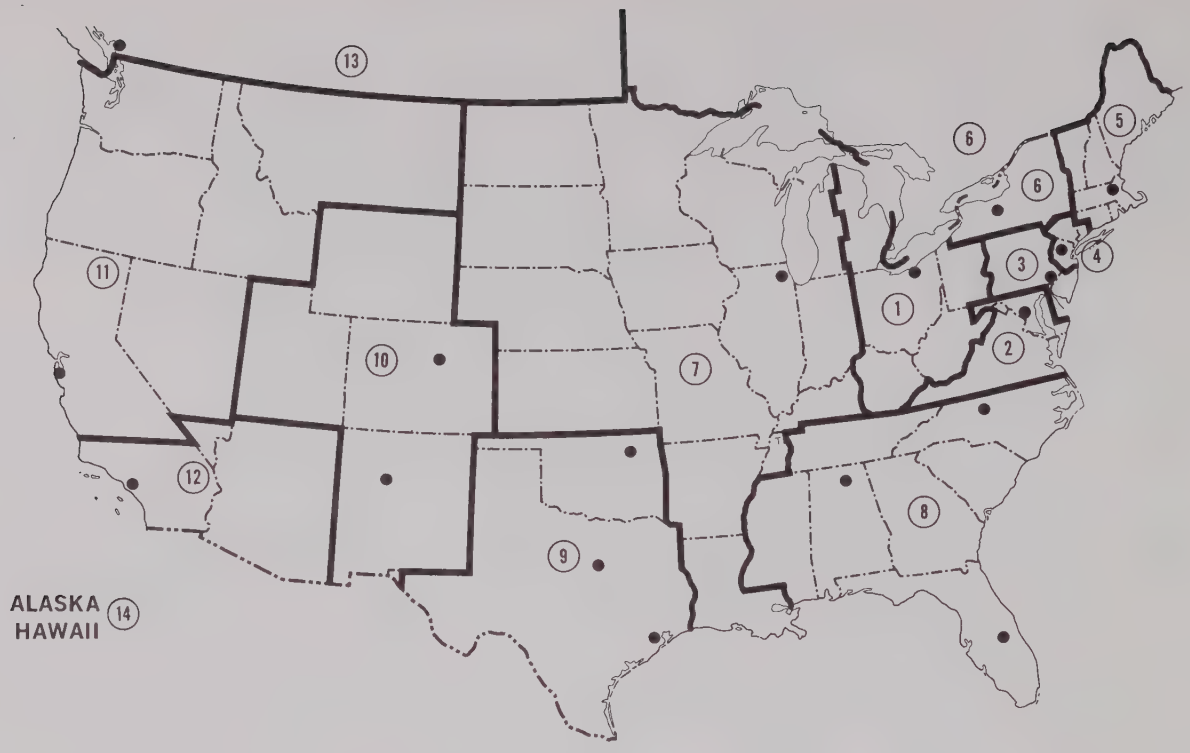
TELEPHONE: (021) 28-11-68



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1■ KEITHLEY INSTRUMENTS, INC.
28775 Aurora Road
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(216) 248-0400

2 KEITHLEY INSTRUMENTS, INC.
5817 Baltimore Boulevard
Riverdale, Maryland 20840
(301) 277-5111

3 KEITHLEY INSTRUMENTS, INC.
101 East Lancaster Avenue
Wayne, Pennsylvania 19087
(215) 687-1170

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(303) 761-0101

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Zenith 957

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12■ KEITHLEY INSTRUMENTS, INC.
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(213) 784-1159

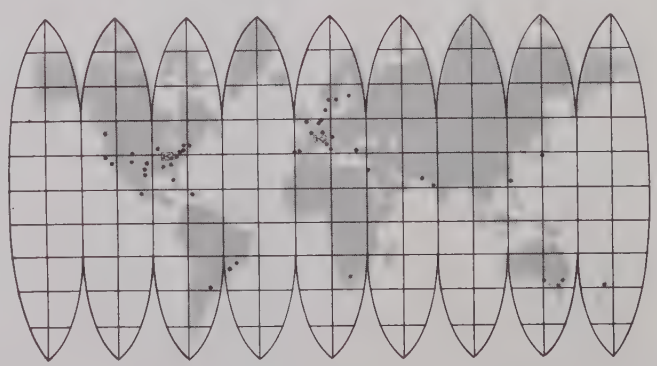
13 AURORA TECHNICAL INDUSTRIES, LTD.
#2-650 Clyde Avenue
West Vancouver, British Columbia
(604) 922-0136

14 NO REPRESENTATIVE
(See 1)

■ Authorized Service Center.

european services

Keithley has a manufacturing facility in Germany and a warehouse and office in Switzerland to provide prompt delivery in the European area. The facilities, staffed by Keithley field engineering personnel, give on-the-spot assistance to your Keithley representative so that he may better serve you. A list of the worldwide Keithley representatives is given on the back.



KEITHLEY INSTRUMENTS, INC.
28775 AURORA ROAD • CLEVELAND, OHIO 44139
TELEPHONE: (216) 248-0400
TELEX: 98-5469

LITHO IN U.S.A.

REPAIR AND CALIBRATION FORM

For repair or calibration, please fill out this form and return it with your instrument to:

Sales Service Department
Keithley Instruments, Inc.
28775 Aurora Road
Cleveland, Ohio 44139

R-_____
Do not write in this space.

User's Name _____ Telephone _____ Ext. _____
Company _____ Address _____
Division _____ City _____ State _____ Zip _____
Date _____ Model No. _____ Serial No. _____

1. Reason for Return
   - ☐ Repair and Recalibration
   - ☐ Recalibration only (No report, except as specified in item 4 on reverse)*

   *If repairs are necessary to meet specifications, they will be in addition to the calibration.

2. Calibration Report Desired
   - ☐ Report of Calibration Certified Traceable to N.B.S.
   - ☐ Calibration Report
   - ☐ Certificate of Compliance
   - ☐ None

   (for details, see reverse side of this form)

3. To help repair the instrument, briefly describe the problem: _____

4. Is the problem ☐ Constant ☐ Intermittant
   Under what conditions does the problem occur:
   a) Control setting _____
   b) Approx. Temperature _____ °F
   c) Approx. Temperature variation ± _____ °F
   d) Approx. Humidity (high, medium, low) _____
   e) Line voltage _____
   f) Other (such as line transients, line variations, etc.) _____

5. Please draw a block diagram of the system using the Keithley. List any other pertinent data which can help in the repair. Include charts or other data if available.
   Signal Source _____
   Source Impedance _____
   Readout Device:
   - ☐ Recorder
   - ☐ Oscilloscope
   - ☐ Other
   - ☐ None

   Lengths & Types of Connecting Cables _____

6. What repairs or modifications have been made on this instrument which are not on file with the Keithley Repair Department? _____

7. Please enclose any other pertinent data and charts which you feel might help the Repair and Calibration Department

_____ Signature _____ Title

CALIBRATIONS AVAILABLE AT KEITHLEY INSTRUMENTS.

Listed and defined below are the four types of calibrations and their associated report formats which are presently available at Keithley Instruments. They fall into the following categories:

1. Report of Calibration Certified Traceable to the National Bureau of Standards
2. Calibration Report
3. Certificate of Compliance
4. Recalibration

All calibration and certification performed by Keithley Instruments is in accord with MIL-C-45662A.

Prices shown below are in addition to repair charges for any work necessary to place a customer's unit into first class condition prior to the calibration.

1. Report of Calibration Certified Traceable to the National Bureau of Standards.

   This is a completely documented report, including all basic errors or deviations from nominal settings on appropriate ranges, terminals, dials, etc. Work is performed using the primary standards of the company with secondary transfers kept to a minimum. The NBS test numbers for the latest recalibration of the primary standards are furnished.

   By definition, the above is performed in our Standards Laboratory so that random operator induced error is minimized and maximum protection to the equipment used is maintained.

   This type of calibration is not recommended for instruments with a basic inaccuracy of 1% or greater. The precision involved in this report makes it uneconomical for such instruments. The Calibration Report listed below (No. 2) would be better suited in this case.

   As of 12/1/67 the Report of Calibration Certified Traceable to the National Bureau of Standards is available on the following instruments at the prices listed:

Model 140	$325	Model 5155 (Complete Set)	$265
Model 260	$220	Model 5155-10^8	$ 45
Model 261	$280	Model 5155-10^9	$ 45
Model 515	$520	Model 5155-10^{10}	$ 45
Model 630	$250	Model 5155-10^{11}	$ 55
Model 660A	$200	Model 5155-10^{12}	$ 55
Model 662	$250	Model 5155-10^{13}	$ 75

2. Calibration Report.

   This report shows only the cardinal range, terminal, dial, etc. errors as determined by production calibration equipment and personnel. The production equipment is maintained traceable by transfer techniques against the primary standards maintained by the company. We attest to this fact and list basic deviations from nominal but the conditions of calibration are not as precisely controlled as the previous report nor are NBS test numbers supplied.

   This report is available for any instrument in our line. As of December 1, 1967, only the following price has been established for this report:

   Model 261 . . . . . $50

   Prices for other units can be estimated upon request.

3. Certificate of Compliance.

   This is merely a restatement of the basic guarantee that the instrument was calibrated on equipment that is maintained by our standards personnel against primary standards. No report is issued.

   This Certificate of Compliance is available at no charge for any instrument with the exception of the Model 261.

   A newly purchased Model 261 or one returned for repair or recalibration is automatically supplied with a Calibration Report (as described in (2) above). The nature of this instrument makes it necessary to complete this report to ascertain specified accuracy. This Calibration Report is forwarded to the customer with the instrument. The $50 charge is incorporated as part of the normal calibration charge of the Model 261.

4. Recalibration.

   This is a recalibration of the instrument according to our factory calibration procedures. The prices for this as of December 1, 1967 are as follows:

   Model 260 . . . . . $75 (No report supplied. A Certificate of Compliance can be had at no charge if requested).

   Model 261 . . . . . $50 (Calibration Report as described in (2) above is supplied. See (3) for explanation).

   All other instruments are on a time and material basis for the particular unit involved.

CHANGE NOTICE

March 13, 1969 MODEL 148 NANOVOLTMETER

Page 51. Change to the following:

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Q15	2N1605A	02735	TG-16	22
Q16	2N651	04713	TG-9	22

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